City of Leeds.

REPORT

ON

Experiments in Sewage Disposal

Carried out at the Knostrop Sewage Works, Leeds, from 1898 to 1905.

BY

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AND

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PREFACE.

In November, 1904, I retired from the Corporation of Leeds, and consequently from the Chairmanship of the Sewerage Committee, which position I had held from 1897.

During the whole of this period interesting experiments had been carried out at the Knostrop Sewage Works in connection with various methods of sewage disposal, and as only one interim report had been issued (in July, 1900), it seemed fitting that at the end of my official connection with the Knostrop Works, I should issue a complete report on the whole of the experiments, which by the public spirit of the Leeds Corporation had been carried out from 1897 to 1905.

I have to acknowledge the generous confidence with which the Corporation has left in my hands the initiation and the direction of all this work, in which I have been happy to have the able assistance of Mr. W. H. Harrison, M.Sc., who was appointed in 1898 Chemist in charge of the Works, and who is responsible for all the analytical work referred to in this report.

It is necessary to note that all conclusions and opinions given in these pages are based upon experience with Leeds sewage, and are not necessarily applicable to other sewages which may differ considerably from it.

Notwithstanding this necessary reservation, the report, which gives the details and results of careful experiments in sewage disposal over a large range of modern methods, will doubtless have a widespread interest outside the City of Leeds.

T. W. H.

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REPORT

ON

Experiments carried out at Knostrop,

1898-1905.

Statistical and Historical Notes.

The City of Leeds contains within an area of 21,572 acres a population estimated at this date to be 450,000. Population.

The district is hilly, varying in level from 70 feet above the sea at the river, to over 500 feet. It is traversed by the River Aire. The whole of the City, excepting Rodley and a portion of Bramley, is in one sewerage system, of which the outfall is in the Thorp Mill Pool, at Knostrop, $2\frac{1}{2}$ miles from the Town Hall. For the excepted parts, which together have an estimated population of 4,500, a system of irrigation works is now being laid out on 60 A. 1 R. 23 P. of land, adjoining the River Aire, at Newlay. The system of sewerage in both parts is that known as the combined, there being no separate drains for surface water. System of Sewerage.

It is estimated that three-fourths of the population use water closets or trough (water) closets, but the privies used by the remainder are being replaced by water closets, which in new buildings are now compulsory. Domestic Sewage.

Trade effluents.

Most of the trade liquid refuse finds its way into the sewers. Some of the trade effluents are of large volume, and seriously affect the treatment of the sewage, as for instance, those from Tanneries, Wool Scouring and Dyeing, Copper and Galvanizing works. While the policy of the Council has been to encourage trade by receiving trade effluents into the sewers, it is evident that their admission should be conditional upon (1) effective means being taken by traders to precipitate the solids in their refuse; (2) the discharge being so regulated that there should be no sudden rush of a considerable volume, but rather a gradual and steady flow spread over the 24 hours; (3) that an inspection manhole shall be provided; (4) that no discharge should be allowed, which, either by its temperature or other character, would injure the sewers, promote decomposition, or prejudicially affect the treatment of the sewage.

Regulations to this effect have been adopted and applied in the case of many important works. The greater number of the effluents coming into the sewers from a multitude of small sources are of too small volume to make it practicable or even necessary to apply these regulations, and it must be added that the present state of the law on the subject makes it difficult to apply them at all to old connections to the sewers if the parties are unwilling. There is urgent need of legislation on the lines of the third report of the "Royal Commission on Sewage Disposal."

Leeds possesses an abundant supply of good water, the present consumption being at the rate of upwards of 17 million gallons a day, five of which millions are supplied for trade purposes and eleven millions are consumed for domestic purposes. This works out to 40 gallons per head of population. Almost the whole pours into the sewers.

Volume of Sewage.

The volume of sewage varies, of course, from hour to hour. Apart from rainfall, the maximum flow occurs at about mid-day,

and the minimum flow at night. The normal dry weather flow may be taken at the present time to average 16 million gallons for the 24 hours. The rate of flow rises to over 25 million gallons in the day, and falls to below nine million gallons in the night. The volume of the sewage is, of course, very largely affected by rainfall, a very slight rain, say $\frac{1}{20}$ of an inch per hour, will increase the flow to a rate of 60 million gallons per 24 hours. To prevent greater rainfalls reaching the outfall sewer than it can take, a system of overflows and leaping weirs is carried out in the City. By these each drainage area discharges its rainfall into the river after the sewage has been many times diluted with it.

From 1842 the question of constructing a system of main drainage was under consideration by the Corporation. In 1850 contracts were let for main sewers in accordance with a scheme by Mr. Leather, and the works were completed in 1855. The sewage of the dense part of the City having thus been brought to one outfall, complaints began to be made of the serious nuisance arising in the river, which was then relatively free from impurities. There were plenty of minnows, roach, dace and eels in the Aire up to 1860, before the river as it passes through Leeds had been ruined by the sewage and trade refuse of Bradford. Historical.

In 1867 Mr. Filliter, C.E., was consulted, and a scheme was proposed to carry the sewage by a gravitation conduit 27 miles long to 2,000 acres of land at Thorne Waste. The cost of the scheme was estimated at near £292,000. This does not seem to have been approved, and in 1869 and 1870 deputations visited London, Birmingham, and other places. Early in 1870, the Corporation having proposed to sewer the out-townships, riparian owners below the sewage outfall became alarmed, and obtained an injunction restraining the Corporation from allowing sewage to flow to the Aire until it had been purified, so as not to create a nuisance or become injurious to the public health.

A B C Process.

Immediate steps were now taken to deal with the matter, and from 1870 to 1874 a number of experimental systems were tried, the most important of which was that known as the A B C system.

At that period all that was aimed at was to clarify the sewage—by the complete settlement of its suspended impurities. The patentees of various precipitants suggested that the manurial value of the sludge would create a wide demand for it at a profitable price, but it was found that as sludge (90 % water) it had no value at all, and must first by drying or pressing at considerable cost be brought into a condition to be handled. Even in this state it would not bear the cost of carriage beyond a short distance, and the farmers of the neighbourhood soon discovered that they were the only possible customers and could make their own conditions. After a short time they only fetched the dried sludge when it was convenient to them to take any, paid nothing for it, and required it to be loaded for them into the carts.

Lime Precipitation Works.

In these circumstances the use of various patented precipitants was abandoned, and the lime process upon which no royalties were payable was adopted.

In 1874 the Corporation completed the present Knostrop works at a cost of £57,000, including the site, buildings, engines, boilers and tanks.

For some years very fair results were obtained, but in the last thirty years there has been a great development of the population and sewage of the City, and the works laid down in 1874 have remained substantially as they were at first constructed, except that in the spring of 1897, as a provisional measure pending the settlement of a new scheme, the Council sanctioned the expenditure of £28,000 for the building of 7 additional tanks. The 12 old tanks had a water area of 1⅗ acres and a capacity of 2½ million gallons. The new tanks have an area of 2 acres and a capacity of 3 million gallons.

No doubt with this area and the use of an adequate proportion of precipitant, fair sedimentation results would have been obtained ; but it was soon found, when the new tanks were (about 1900) brought into use, that it was quite impracticable to deal with the amount of sludge produced. The whole site available is only 26 acres, and a large part of it is taken up by engine and boiler and lime houses, a row of houses for the staff, and by the tanks themselves. There has never been any plant for pressing the sludge into cake—while a drying apparatus put up some years ago was found to be prohibitively costly, and has since been removed. Every square yard of the site available is used for lagoons in which the sludge is air-dried, a process which requires six to twelve months to bring the sludge into a spadeable condition, and is liable to produce a nuisance.

Sludge difficulty.

If the whole of the Leeds sewage were effectively settled by lime, some 500 tons of 90 % sludge would be produced per 24 hours. As it is found quite impossible to deal locally with such a volume, the Sewage Committee has been compelled in recent years to use only a small amount of lime, and to carry out an imperfect settlement of the suspended matter in the sewage.

Even if a sufficient pressing plant were provided, there would be such a production of sludge cake, probably 150 tons a day, that it would be impossible to dispose of it to farmers locally. The distance and the water carriage available make it impracticable to convey the sludge to the sea, while a proposal to burn the sludge after pressing into cake has been objected to on the ground that it might give rise to nuisance, if carried out on a large scale.

Now, if by the acquisition of land and the provision of an adequate sludge pressing plant, it became possible to remove the pressure of the sludge difficulty, it is necessary to point out that a process of precipitation, useful so far as it goes, is quite insufficient for sewage purification. The effluent,

Something required beyond Settlement.

though it should be fairly clear and free from smell as it flows from the precipitation tanks, contains much organic impurity in solution, and is liable to decomposition and putrefaction. Indeed, only about one-half of the impurities are removed by precipitation. It is now generally recognised that further purification is necessary, and that precipitation must be followed by land filtration, or where suitable land is not available, by artificial filtration, so that besides the removal of impurities in suspension, those in solution shall also be greatly reduced.

It became necessary, therefore, for the Corporation of Leeds to look out for a new and larger site for Sewage Purification Works, and to consider what system should be adopted in order to reduce the production of sludge and to secure more complete purification, especially of the organic matter in solution.

In 1894 a deputation visited the most important Sewage Disposal Works and Sewage Farms in the country, and formed the opinion that Broad Irrigation, that is, dealing with the sewage upon land without previous precipitation was the best process of sewage purification. For the large and growing population of Leeds, some 4,000 acres would be required, but on enquiry it was found impossible to obtain so large an area of suitable land within practicable distance of the City. The cost of such a scheme was found to be very large, in view, not only of the area required, but of the necessity of pumping the large volume to be dealt with, or of making a very long and costly conduit if a gravitation scheme were to be adopted.

Position in 1896.

This was the position of affairs in the end of 1896, when a new Sewerage Committee was appointed, with Colonel Harding as its Chairman.

Just at this time attention was drawn to experiments which were being carried out on what were called "Biological Lines" at Barking (London) Sewage Works, and at Sutton (Surrey). The Committee twice visited these works, and Mr. Dibdin, the eminent chemist, who was directing the works at Sutton foreshadowed the possibility of dealing with sewage on biological filters without production of sludge, and with results far superior to those of chemical precipitation; while the cost of the process, as it was then believed, would be relatively small. Barking Experiments.

In the early experiments with artificial beds, the true principles of action were not at once seen. In his first experiments at Barking Mr. Dibdin found that in passing settled sewage continuously over coke beds—3 ft. deep—excellent results were at first obtained, but these in a very few days rapidly fell off, and the bed became putrid. The experiment seemed a failure, and was necessarily stopped. But after some weeks the bed was found on examination to be sweet again, and capable of effectually purifying sewage passed over it. This shewed that *aeration* was essential to maintain the conditions under which bacterial action could be carried on, and experiments were then made in passing sewage into the beds intermittently; the sewage was allowed to stagnate in the bed for some two hours, and was then discharged, the bed resting empty for several hours to secure aeration. About eight hours were thus required to deal with one filling, and the process could therefore be repeated thrice in the 24 hours. In this way it was found that the action of the bed might be carried on indefinitely.

Land filtration is also an intermittent process. Sewage cannot continuously flow over the same land with good results. After a period, varying with circumstances, the sewage is turned off and flows over another area.

In the experiment at Barking the bed was dealing with sewage from which the solids in suspension had been mostly removed by a process of chemical precipitation, which of Dibdin's Sutton Experiments.

course involved the production of a large volume of sludge. It occurred to Mr. Dibdin that it would be useful to try whether Bacteria Beds could deal with crude sewage. At Sutton he was able to try this very interesting experiment. Two Bacteria Beds were used; one of coarse coke, and one of small coke (coke breeze). The method of working was in eight hour cycles, similar to that already described. The sewage passed to the coarse bed was crude except that a half inch iron screen kept back the larger solids.

The effluent from this bed passed on to the second or fine bed, and the final effluent was practically free from suspended matter, slightly opalescent and free from smell, while the purification obtained was 80% for the joint action of both beds as measured by the oxygen absorbed test.

It remained to be seen whether the ordinary periods of rest would suffice for the digestion of the suspended matter left in the bed, and if not whether its accumulations would be disposed of by exceptional and longer periods of rest; and further whether results obtained with mere domestic sewage at Sutton would also be obtained with the sewage of Leeds, which to the extent of a third of its volume consists of trade effluents from chemical works, tanneries, wool washing, dyeing, etc.

Mr. Dibdin called in to advise.

This could only be ascertained by experiments at Leeds, and therefore in July, 1897, the Committee called in Mr. Dibdin to advise them in their first experiment with bacteria beds, and he also carried out on their behalf some laboratory experiments on a small scale for the purpose of testing specific samples of Leeds trade effluents, notably tannery effluents and the iron liquor from chemical works.

This report of August 23rd, 1897, states that he found in dealing with iron liquor by itself, that it exercised a strong anti-septic or sterilizing action. When the liquor

however was diluted with domestic sewage, the bacterial action, though to some extent checked, was not stopped, but nitrification did not proceed with its usual ease, oxygen being absorbed by the iron salts, and to that extent not available for oxidizing the organic matter.

With samples of average Leeds sewage, containing iron liquor, tan refuse, and other trade effluents diluted with domestic sewage, good results were obtained on the small experimental beds, giving 80 per cent. of purification as the measure of the work of the double beds.

In the case of tan liquors alone, undiluted by sewage, it was found that the effect of this double treatment, first on a coarse and then on a fine bed, gave nearly 80 per cent. purification, and removed the solids in suspension.

First Leeds Experiments with Crude Sewage on Contact Beds.

The first laboratory trials were so far encouraging that the Committee decided at once to provide a couple of experimental beds—a primary and a secondary—on a scale sufficiently large to give practical results. Beds of this kind, which are filled with sewage and then allowed to stand full for a certain time so that the sewage is brought into contact with the aerobic bacteria on the surfaces of the coke or other material used, before the sewage is allowed to run out, are referred to as contact beds in this report, in order to distinguish them from bacteria beds which are used to percolate sewage through the coke—experiments with which are detailed further on. The area of each bed was roughly $\frac{1}{8}$th acre. The primary bed was filled with coke not less than 3 in. diameter, except at the bottom, where larger coke was used to cover the agricultural drain pipes which conveyed the sewage to the outlet valves. The secondary bed was filled with fine coke between $\frac{1}{4}$ in. and $1\frac{1}{2}$ in. diameter. The depth of the primary was 5 ft. and that of the secondary 6 ft. In order carefully to measure the varying capacity of the beds in their working, the sewage was passed through an iron tank of known capacity carefully graduated.

As at Leeds the disposal of sludge has always been a great difficulty, the aim of the first experiments was to ascertain the possibility of treating Leeds crude sewage on bacteria beds—to find out if the bacterial action would be able to digest the suspended matter left behind in the coke—and, if not, whether occasional long rests of several weeks would be able to safeguard the attainment of this result—do away with sludge production, and maintain a constant water capacity in the beds.

First Trial. The sewage was first turned on to the beds on October 2nd, 1897. Absolutely crude sewage was used, the only matters

kept back being those retained by the iron grating in the screening chamber on the main intercepting sewer, which grating consists of bars with one inch spaces.

At first the beds received only two charges a day, but the pumping arrangements were modified to permit of more rapid filling, so that by December 17th it was possible to give three fillings in each 24 hours in cycles of 8 hours, as follows :—

1	hour	filling.
2	„	standing full.
1	„	emptying.
4	„	resting empty.
8		

The action of the beds as they got into condition steadily improved, until in December the analytical results obtained were very good; and, notwithstanding the increased work thrown upon the beds by the triple fillings per day, the results for January shewed no falling off.

The effluents from the fine bed had no smell, except at times a slight earthy odour. The first flow from the fine bed was always cloudy, and in some cases turbid, but it cleared more or less soon according to the varieties of sewage being treated; the latter part of the flow was always very clear. The average samples were for the first month cloudy, later opalescent, and in December and January almost clear when drawn off. On being kept they always cleared within 24 hours, but the clearing was coincident with a deposit in the bottles of a reddish-brown flocculent matter, which on examination proved to be largely iron compounds. This, as the effluent comes off, is in solution in the ferric state, and precipitates, when the effluent stands, as hydrated ferric oxide. The deposit is due to the very large quantity of iron liquor which comes down with the sewage.

The analytical results were satisfactory.

After four months working, however, the primary bed was found to be unmistakably sludging up beyond expectation. This was considered to be mainly due to the fact that the organic matter in suspension in the sewage was not being digested fast enough. But it no doubt was also due to some extent to the falling or breaking up, or settling of the coke, evidenced by the necessity for placing additional coke to raise the bed to its original level. In the four months the capacity of the bed had been reduced to nearly half.

Another difficulty was met with in dealing with crude sewage, that especially in the neighbourhood of the distributing channels, the surface of the rough bed became coated with a felted mass consisting of fragments of paper, a large quantity of fibre which comes down from wool works, and other solids mixed with the smaller particles which usually go to form sludge, and that this mass spreading over the surface of the bed, prevented the sewage, with its suspended matters, passing down into the body of the bed, and to a great extent also interfered with effective aeration. From time to time it became necessary to turn over the coke to a depth of one or two feet, so as to bury the surface accumulations, and to bring to the top a new surface of coke. This, together with the evidence that the rough bed could not, without special periods of rest, digest all the solid matters brought to it by the sewage, pointed to the necessity for some preliminary straining which should keep back paper, fibre, tea leaves, matches, and other grosser solids which are too slowly disintegrated and broken down, especially if they are retained on the surface.

For the purpose of providing straining apparatus the work was stopped on February 2nd, 1898, and the beds given a rest for a fortnight.

The average of suspended matter going into the primary bed at this period was 37·2 grains per gallon, and the effluent from it contained an average of 11·9 grains, so that 25·3 grains per gallon were left in the primary bed. A calculation based on these figures and on the reduction of capacity went to shew that the digestion of suspended matter was only about 40 % of what was left by the sewage.

The gross capacity of the primary tank before any coke was put in had been 175,000 gallons—and the first net or water capacity after the coke was put in had been 83,000 gallons. **Reduction of Capacity.**

The fortnightly measurements showed a steady reduction, until after four months' working the capacity on February 2nd had fallen to 45,000 gallons.

Would the fortnight's rest which was now given restore the capacity? It is evident that during the rest the chemical change or digestion of the accumulated matter was proceeding, just as it does in a hot bed, for after the fortnight's rest, and before re-charging, the temperature at the bottom of the rough bed was 77° Fahr., the atmospheric temperature at the time being 38½° Fahr. On re-starting the work, a measure was taken, not at the first, but at the second filling, and the capacity was found to be 56,000 gallons, or an increase by the rest of 11,000 gallons.

This seemed at the time to point to the possibility of treating crude sewage and consuming the sludge, if periods of rest were provided, say two weeks out of five, the accumulation in the winter months having been at the rate of about 2,000 gallons a week.

A screening apparatus having been set up, it was found very effective in removing the paper (mostly in very small pieces), vegetable matter, and fibre, and the difficulties of distribution

of the sewage over the rough bed which had been met with in dealing with the unscreened sewage were very much reduced. Although the quantity of the solids kept back by the screen appeared bulky, they were found, on careful measurement, as brushed from the screen, only to amount to an average of $2\frac{1}{4}$ cubic feet, or about 14 gallons per filling in the day, and only half a cubic foot, or about 3 gallons, in the night. The screenings, consisting as they did mainly of paper, woody matter and fibre, were found to be easily burned when dry, and there was no difficulty as to storage, for gardeners were glad to fetch them away for use in garden frames.

It was anticipated that by screening, and thus improving aeration, the accumulation in the rough bed would be considerably reduced, but the results in this direction were somewhat disappointing.

On re-starting on February 18th the capacity was 56,000 galls.
And on April 27th it had fallen to ... ... 40,000 „
A week's rest was then given—which increased the
capacity to... ... ... 46,000 „

and instead of three fillings a day, two only were now given until June 16th, the night filling being omitted. This night filling would not bring much suspended matter, so that the two day fillings would leave in the bed nearly as much as did the previous three fillings, but the additional 8 hours' rest in the 24 was of great assistance; for, while on May 5th the
capacity was ... ... 46,000 galls.
this had only by June 16th been reduced to ... 43,000 „

The work was necessarily stopped on June 16th, because of some excavations required in the immediate vicinity of the beds for other works which were then being constructed.

Effects of Rest.

While the enforced rest from June 16th to July 25th was unfortunate, it was felt that it would be useful in giving information as to the restoring effect of a long rest of six weeks.

At the end of ten days, the temperature inside the primary bed was found to be 82°, that of the atmosphere at the time being 55°. After three weeks the primary bed was dug down to a depth of 3 ft., and the coke was found to be dry to that depth, but appeared still to have some moisture below. At the end of a month the bed was again dug down for the purpose of making a man-hole, and was found to be dry to the bottom, and no sludge was found there. It would seem that beyond the first fortnight the further rest did no good, for the drying up of the coke would probably involve the destruction of the bacterial life, and put the bed in the same condition as a new one. In fact, for a fortnight after re-starting on July 25th, the effluent was more turbid and otherwise less satisfactory than it had been. The capacity of the rough bed when the work was stopped on June 16th was 43,000 gallons. A measure taken on July 28th gave a result of 56,000 gallons, or 13,000 gallons increase. It is probable that this increase would have been obtained by three weeks' rest as well as by hat of thirty-eight days.

Difficulties with Trade Effluents.

The work of the beds was then continued with two fillings of screened sewage a day on exactly the same lines as before the interruption. At this period considerable trouble arose from the large volume of strong dye which came down pretty regularly at about the time for filling the beds. The dye which comes down occasionally at the times when vats are emptied, deeply discolours the whole volume of the sewage, and occasionally astonishing volumes of foul trade effluents have to be dealt with. In one instance a large quantity of what was apparently printing ink actually choked up the pumps.

It is necessary to maintain a systematic inspection of the trade effluents flowing into sewers, with a view to their regulation. It is possible that in some cases the flow is the result of waste unnoticed by the manufacturers themselves.

At the end of a fortnight another measure of capacity was taken, and shewed a quite exceptional reduction of 10,700, much the largest which had been met with. The only explanation which occurs is that during this fortnight there was heavy rain after long drought, and probably large quantities of organic matter were brought down by the washing of the roads, gullies, etc., besides considerable quantities of grit and other mineral matter. Some of the mud in the distribution channels was washed and found to contain sand, fine ashes, &c.

The work at two fillings per 24 hours was continued until September 8th, 1898, by which time the beds had been working over eleven months with seven days' rest—from April 27th to May 5th—and an enforced rest from June 16th to July 25th, in all 45 days' rest.

Results.

The original sewage capacity had been...	83,000 galls.
On July 28th, after the long rest, it was	56,000 „
On September 8th it was	41,000 „

or a loss over the whole period of about 50%.

The effluent from the secondary bed, except for the first fortnight after the long rest, and during the heavy flow of dye, continued to be satisfactory. All the samples taken daily were kept for months in closed and open bottles; they all remained clear and sweet, notwithstanding the flocculent deposit in the bottles which has been already referred to. The effluent remaining in the outflow basin became beautifully clear during the rest between the fillings, and carp originally put into it in November 30th, 1897, continued alive and well. There was abundant green growth in the trough and no sewage fungus.

The average of the analyses over the whole period gave a purification, as measured by the Albuminoid Ammonia, of 86 %; and as measured by the Oxygen absorbed, of 84%.

Experiments with Partially Settled Sewage.

In order to avoid the danger of grit, road detritus, or other mineral matter reaching the beds, it was evidently necessary that the crude sewage should first pass through a settling tank.

As no data were available in connection with the settlement of Leeds sewage, the following interesting experiment was made with stagnant settlement.

A tank of a quarter million gallons capacity was filled by a quick rush of sewage and then allowed to stagnate, samples being taken every half hour. Stagnant Settlement.

The following average results were obtained from several trials:—

Suspended solids in the crude sewage	...	42 grains per gall.
„ „ after $\frac{1}{2}$ hours' settlement		17 „ „ „
„ „ „ 1 „ „		12 „ „ „
„ „ „ $1\frac{1}{2}$ „ „		11 „ „ „
„ „ „ 2 „ „		11 „ „ „

This shows that a quite short period of settlement throws down more than half of the suspended matter, but that the settlement of the light finely divided matter is beyond a certain point very slow indeed, unless precipitants be used.

From September 8th, the beds received sewage settled one hour, containing only 12 grains per gallon or less than one-third of the quantity which hitherto had been going into the beds. At the end of a fortnight the capacity of the primary bed had risen from 41,000 gallons to 47,000 gallons, and at the end of another fortnight the capacity was still 46,000 gallons. Of course, a large quantity of sludge was left in the settling tank.

As at this time the aim was to see how much suspended matter the bed could deal with, the sewage for the next fortnight was only settled half-an-hour carrying to the bed 17 grains per

gallon, or less than half that in the crude sewage, and during this month the capacity of the primary bed fell from 46,000 to 44,000 gallons. During the six weeks the two fillings a day were given, the night filling being omitted.

Flowing Settlement.

The pumping required for stagnant settlement proving inconvenient, flowing settlement was now substituted at first at such rate as would leave about the same amount of suspended matter in the sewage.

The rate of flow was, however, increased after a few weeks, so that only a few grains, mostly of mineral matter, which of course bacterial action could not reduce, were left in the settling tank, and the beds were made to deal again practically with crude sewage.

Beds rested on Sundays.

Instead of daily omitting the third or night filling, the beds now received three fillings in the 24 hours but were allowed to rest on Sundays. Working on these lines, the capacity of the primary bed had by March 15th been reduced to 27,600 gallons.

The quality of the filtrate was certainly better as the bed reduced in capacity, the silting up of the coke no doubt causing it to act more perfectly as a mechanical filter, keeping back solids in suspension, and so also increasing the rate of the reduction in capacity.

The original sewage capacity after the coke had been put into the tank was, on October 2nd, 1897 ... 83,000 gallons.
It had fallen on March 15th, 1899, to ... ... 27,600 „
that is, to one-third of the original net capacity.

It was not considered advisable to let the experiment continue on the same lines, for the choking up of the primary bed would now be very rapid. It was thought more useful to see how far the fillings, that is the work of the filter, would have to be reduced in order to maintain the present capacity.

The beds had been working for some months at three fillings a day, with a rest of one day in seven.

Beds rested two days a week.

Two days' rest in seven were now given, viz., on Sundays and Wednesdays. On the day following the rest day the filtrates were exceedingly good, but on the following days they became opalescent and generally deposited iron.

By May 7th the capacity had fallen to 22,700 gallons, and as this method of working with two days' rest out of seven had not prevented a further reduction of capacity, the beds were now rested on alternate days, still giving three fillings on the working days. The capacity which on May 7th had been 22,700 gallons was in this way of working found to be increased at the end of June to 25,600 gallons. The filtrate continued to give good analytical results, although depositing iron on standing.

Beds rested on alternate days.

AVERAGE OF ANALYSES REFERRING TO PERIOD FROM MAY 7TH TO JULY 5TH, 1899.

GRAINS PER GALLON.	Total Solids.	Solids in Suspension.	Free NH_3.	Alb. NH_3.	Oxygen absorbed (4 hrs., 80° F.)	Nitrogen as Nitrates.
Crude Sewage	113·4	42·5	2·41	·933	8·81	—
Filtrate from Rough Bed (No. 1)	73·0	11·6	1·24	·311	2·33	—
Filtrate from Fine Bed (No. 2)	67·1	1·7	·337	·071	·448	·474
Percentage Purification...	—	96%	86%	92%	94%	—

It will be seen that working with 3 fillings on alternate days—that is an average of $1\frac{1}{2}$ fillings a day—there was an increase of capacity. The rate of work was now further reduced to one filling per day every day, and this was continued from July 1st, when the capacity was 25,600 gallons to October 7th, the capacity slowly rising to 26,900 gallons. This increase was more apparent than real, for owing to the longer periods of rest between the fillings the beds would have time to empty themselves better. The most that can be said is that working with

crude sewage, at one filling a day, with an average of 25,000 gallons per filling, the capacity of the bed had been maintained. It is important, however, to remember that this series of experiments took place during the warmer months of the year.

Primary Bed Choked.

From the beginning of August considerable difficulty was met with in filling the primary bed. The sewage sank very slowly into the coke—and began to pool over the surface—although it was several times dug over. By October 7th this condition had so far increased that the series of experiments carried on from October 2nd, 1897, to October 7th, 1899, in treating crude sewage on double bacteria beds was brought to a close. Except for a few weeks during the experiments in settlement, the beds had been dealing, at first with absolutely crude sewage and later with sewage which was crude except for the settlement of grit and other mineral matter, and the screening off of the grosser solids.

During the last three months the outlet valves of the primary bed were opened at full on discharging the bed with the object of seeing whether or not the greater rapidity of emptying would help to wash out the bed. Although this procedure was continued until October 14th no appreciable effects resulted. Before this the valves had been opened to such an extent as would allow the bed to discharge in one hour.

The sewages during this period varied exceedingly in strength, and in October, owing to the dry summer, they became very strong. The average amount of suspended matter in the sewage was 46·4 grains during this experiment, but owing to the beds only receiving one filling per day, and this during a portion of the day when the variations in the strength of the sewage are very great, it was found that they really received an average of 55·4 grains per gallon of suspended matter.

Average of Analyses referring to period from July 5th to October 14th, 1899.

Results.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed (4 hours, 80° F.).	Nitrogen as Nitrates.
Crude Sewage	128·5	46·4	2·17	1·01	9·44	—
Filtrate from Rough Bed (No. 1)	87·7	15·0	1·20	·375	2·96	—
Filtrate from Fine Bed (No. 2)	81·2	2·6	·365	·099	·554	·455
Percentage Purification...	—	94%	83%	90%	95%	—

Analysis of Accumulations.

On March 21st, 1899, in order to learn what was the nature of the deposit which was accumulating in the beds, the rough bed was dug down to the bottom, and a spadeful of the coke was taken from the bottom, middle, and near the top and put into a bucket. The deposit on the coke near the top was of an earthy character, and lower down where it was wetter it took the form of at first a brown, and near the bottom a black odourless slime. On analysis the deposit was found to contain 85 per cent. moisture. Of the remaining 15 per cent. about 7½ was organic matter, some of which was fibrous, and the remaining 7½ was mineral, about half of it being ferric oxide.

This spongy deposit retains much of the water, so that the bed does not empty itself unless long periods of rest are given, and, indeed, it is found that a bed will trickle for days after the main flow has ceased. The drying up of this spongy matter during lengthened rests accounts to a great extent for the increase of capacity obtained on re-starting, which is mostly soon lost.

On October 31st another examination was made after closing the experiment last described and letting the beds rest. The No. 1 Bed was dug down and found choked with a substance closely resembling garden mould, and having no evil odour. It was found to be non-putrescible.

A cubic foot of the material of the bed, after passing through a $1\frac{1}{2}$ inch mesh, was well washed in water so as to free the coke from the adhering deposit, and then sorted out into various sizes by means of riddles. The wash water containing the deposit was then passed through a $\frac{3}{16}$ inch mesh in order to retain the smaller pieces of coke, and the mud remaining was collected on canvas. This mud was dried, weighed, ignited at a red heat until all organic matter was destroyed, and weighed again.

The following is the result obtained:—

	Cubic Ins. By Vol.
Coke rejected by 1 in. mesh and passed by $1\frac{1}{2}$ in. mesh	484·27=28·01 %
" " $\frac{1}{2}$ in. " " 1 in. "	231·60=13·40 %
" " $\frac{3}{8}$ in. " " $\frac{1}{2}$ in. "	32·34= 1·87 %
" " $\frac{3}{16}$ in. " " $\frac{3}{8}$ in. "	34·17= 1·97 %
	782·38=45·25 %
The deposit on the Coke (70 % water)	352·50=20·39 %

The deposit, when dry, gave the following analysis:—

Loss on ignition at a red heat for 5 minutes	= 36·50 %	by weight.
Ferric Oxide	= 30·52 %	"
Sand, &c.	= 15·54 %	"
Carbon present, as Coke	= 16·86 %	"
Other Mineral Matters	= 0·58 %	"

These last items are no doubt due to the degradation of the filtering material.

General observations on the series of experiments hitherto described with contact beds Nos. 1 and 2 will be found further on.

Experiments with Contact Beds Nos. 3 and 4, and Nos. 5 and 6.

Simultaneously with the experiments just referred to, others of an analogous character had been carried on with two other pairs of contact beds Nos. 3 and 4 and Nos. 5 and 6. All these beds were like Nos. 1 and 2—of $\frac{1}{8}$th acre area—but differed in construction, depth and material.

Beds Nos. 3 and 4.

No. 3 was a primary bed filled with finer material than the No. 1 primary, viz., with clinker from the Leeds destructor of a size between $\frac{1}{2}$ inch and 1 inch. The secondary bed, No. 4, was filled with clinker between $\frac{3}{16}$ and $\frac{1}{2}$ inch. The depth of both was 3 feet, and it was believed that, with this shallow depth, there would be better aeration, and that more fillings would be possible per day, so as to pass the same volume per acre as in the deeper Nos. 1 and 2 beds. The arrangements for drainage and distribution were also simpler and cheaper than was the case with the first pair of beds. The distribution was in a thin film all along one side of the bed, and as fibre and mud accumulated on that side the sewage gradually spread itself over the bed and gave fairly efficient distribution. About every three months the surface was forked over.

This second pair of beds Nos. 3 and 4 was started on November 19th, 1898, with three fillings a day and a Sunday rest each week. The sewage was practically crude, for only the grit or mineral matter was settled by a rapid flow through a settling tank.

Until the beds matured the first filtrates were opalescent, and deposited a copious precipitate mainly of basic-iron compounds, but by the beginning of January, 1899, they became clear and colourless, though subsequently depositing iron, and although the analyses were as yet scarcely at their best, green confervoid growths began to appear in the channels which carried the filtrates away.

The original net capacity of the No. 3 primary bed after the coke had been put in had been ... ... 52,000 gallons
At the end of March it was ... . 24,000 „
The beds were then rested a fortnight, and
On April 17th the capacity was ... ... 28,600 „
On May 2nd the capacity had fallen to ... 21,700 „

For the next two months the beds were worked one week at three fillings a day and rested the next week, so averaging 1½ fillings a day for the whole period; and the effect of this reduced working was to maintain and slightly increase the capacity to 22,500 gallons.

Average of Analyses referring to period from May 7th to July 5th, 1899.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed (4 hours, 80° F.).	Nitrogen as Nitrates.
Crude Sewage	113·4	42·5	1·94	·922	8·12	—
Filtrate from Rough Bed (No. 3)	74·2	10·8	·990	·208	1·68	—
Filtrate from Fine Bed (No. 4)	69·9	2·3	·562	·098	·569	·245
Percentage Purification...	—	94%	71%	89%	93%	—

Nitrates were freely produced during the periods of rest, and appeared in the first filtrates.

Occasionally for a month at a time lime was added to the sewage to the extent of three grains per gallon, but no very appreciable effect was produced.

From July, 1899, instead of working the beds on alternate weeks, they were worked on alternate days, with three fillings a day on the working days. The average therefore was 1½ fillings a day as before, and on this system the work was continued right away for 19 months until February, 1901.

The original water capacity of the primary bed at the start in November, 1898, had been ... ... 52,000 galls.

On March, 1899, this had fallen to...		...	...	24,000 ,,
,, April 17th, 1899,	after a fortnight's rest, it was			28,600 ,,
,, May 2nd, ,,	it had fallen to	...	...	21,700 ,,
,, June 28th, ,,	after working	alternate	weeks	22,500 ,,
,, July 27th, ,,	,,	,,	days	24,400 ,,
,, Aug. 24th, ,,	,,	,,	,,	25,000 ,,
,, Oct. 5th, ,,	,,	,,	,,	24,200 ,,
,, Dec. 30th, ,,	,,	,,	,,	18,100 ,,
,, May 21st, 1900,	,,	,,	,,	18,100 ,,
,, Sept. 14th, ,,	,,	,,	,,	17,300 ,,
,, Jan. 10th, 1901	,,	,,	,,	14,700 ,,

Working at three fillings on alternate days, the capacity is seen to have been fully maintained in the summer months, but it continued to fall during the colder weather.

Although this pair of beds had not been overworked, they had in $2\frac{1}{4}$ years lost 71 per cent. of their original capacity, and in the recent months there had been so much difficulty in getting the sewage into the coke that the work was stopped in February, 1901, and on digging down into the primary bed it was found choked throughout its mass. The secondary bed also was considerably choked, the breakdown of the material being in this case largely responsible.

The following is the average of all the analyses made during the whole period of working the Nos. 3 and 4 beds with crude sewage, from which only the grit and other mineral matter had been settled:— Results.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.
Crude Sewage	110·8	42·4	2·10	·945	8·75	—
Filtrate from Rough Bed (No. 3)	82·3	12·6	·920	·289	2·07	—
Filtrate from Fine Bed (No. 4)	73·0	3·38	·586	·108	·655	·261
Percentage Purification...	34·1%	92·0%	72·1%	88·5%	92·5%	—

It will be noticed that the results obtained with contact beds Nos. 3 and 4 were very similar to those shewn by beds Nos. 1 and 2, but it was not found that the shallower beds gave such greater aeration as to make it possible to give a larger number of fillings. The experience gained by this experiment went to show that the volume of sewage which can be dealt with on contact beds for a given area is proportional to the depth—and the results obtained with the deeper beds were rather better than those with the shallower beds.

Contact beds Nos. 5 and 6.

It is unnecessary to give in detail the history of the third pair of contact beds Nos. 5 and 6, which, like all the others, had an area of $\frac{1}{8}$ acre—and, like Nos. 3 and 4, had a depth of 3 feet. Their construction and material were similar to Nos. 3 and 4, but the clinker in the primary bed No. 5 was rather coarser than that of No. 3.

These beds were started on February 27th, 1899, and worked until December 30th, 1900—for nearly two years—with grit settled sewage generally on the same lines as for Nos. 3 and 4.

The net capacity at first was ... ... 53,000 galls.
and at the end of the period it had fallen to ... 11,700 „
a loss of 77 % on the original capacity.

The purification effected was similar to that obtained with beds Nos. 3 and 4, and not so good as that of the deeper beds Nos. 1 and 2.

AVERAGE OF ALL THE ANALYSES FROM FEBRUARY, 1899, TO DECEMBER 30TH, 1900. Results.

GRAINS PER GALLON.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.
Crude Sewage	109·6	41·9	2·16	·971	8·89	—
Filtrate from Rough Bed (No. 5)	81·9	13·7	1·23	·397	2·91	—
Filtrate from Fine Bed (No. 6)	71·5	3·3	·666	·141	·790	·127
Percentage Purification...	34·7%	92·1%	69·1%	85·4%	91·1%	—

In the course of the experiments with beds Nos. 5 and 6, trials were made with different lengths of contact,—that is to say, the sewage was left to stagnate in the beds for longer and shorter periods than two hours, the result being that two hours' contact were necessary, while no better purification was obtained by increasing contact up to four hours. Further increase would probably eliminate the aerobic organisms.

General Observations on preceding Experiments in the Treatment of Crude Sewage, and Imperfectly Settled Sewage on Contact Beds.

In the experiments with the three pairs of contact beds, Nos. 1 and 2, 3 and 4, 5 and 6, the sewage was used at first quite crude, and afterwards was crude except for settling the grit and road detritus, and screening off as far as possible fibre, paper, etc.

It was, in fact, sewage containing the bulk of its suspended matter, and if it had been found practicable to deal with it permanently on contact beds, there would have been no sludge production, for the settled mineral matter and those screened off could be handled at once and carted away, without drying or pressing. The sanguine expectations, however, raised by the Sutton experiments, were not realised at Leeds, because the capacity of the primary beds could not be maintained. Worked at three fillings a day, every day the capacity rapidly fell, and could only be maintained at one filling a day in summer. Leeds sewage can be treated with excellent results on contact beds, but not in the crude state, and not so as to avoid sludge production.

The great bulk of the suspended matter must be first removed. The rate at which contact beds lose their capacity varies directly with the amount of suspended matter in the sewage treated ; it is greater in winter than in summer, and is reduced by increasing the periods of rest.

Sewage contains impurities, organic and mineral, both in suspension and in solution.

The treatment of sewage resolves itself into two parts:

1—Dealing with matters in suspension.

2— „ „ solution.

If a sample of Leeds sewage is filtered through filter paper, the withdrawal of the solids in suspension gives a purification of about 50 per cent.

Chemical precipitation brings about a similar result, from 45 to 55 per cent. purification, though in some cases somewhat better results are obtained on account of the action of the precipitant in throwing down some of the matters in solution.

After the solids in suspension have been removed from sewage there remains a liquid, which may be clear and at first free from smell, but which still contains in solution about 50 per cent. of the impurities originally in the sewage. This liquid on standing or being turned into a stream becomes dark coloured, putrefies, and gives off offensive smells.

Chemical precipitation deals mainly with the suspended matter, and in actual practice accomplishes little in regard to the dissolved impurities; and its effect in regard to the first is at the cost of great production of sludge which has to be dried, or pressed, and removed, and has little or no agricultural value.

Object of Experiments.

The object of the first Leeds experiments was therefore :—

1. To bring about a higher degree of purification than can be attained by mere precipitation with or without chemicals.
2. To see how far it might be possible by bacterial action to do away with sludge production, or at least to reduce it.

The experiments were with double contact beds, a primary and a secondary bed working in pairs, numbers 1 and 2, 3 and 4, and 5 and 6.

This system of artificial filtration was found to bring about a purification of from 75 to 95 per cent., but it is more effective in regard to matters in solution than to those in suspension which are more slowly reduced, and of which the undigested or indigestible portions tend to accumulate and choke the beds.

The filtrate from the primary beds, which is an intermedia and not a final result, was always dark coloured, with some smell, and was usually putrescent in character. The last flow shewed signs of anærobic fermentation, and sometimes deposited sulphur. The process is not, at least in the lower portions of the rough bed, a strictly ærobic one, for the lowest portions are scarcely empty before re-filling begins.

The first flow from the fine beds is usually somewhat turbid and unsatisfactory, owing to insufficient aeration in the lower parts of the beds, and in the channels and pipes; and also to accumulation of solid matter in the neighbourhood of the outlet valves. On the other hand, the last part of the flow is exceptionally good, and therefore all the samples analysed were the average of the whole flow, spreading over an hour, and taken every ten minutes.

As a rule, the primary beds were found to keep back from 65 to 75 per cent. of the solids in suspension, and the effluent shewed a purification of about 65 per cent. The effluent from the secondary beds shewed a purification on the crude sewage of from 75 per cent. to 95 per cent.

From experience gained during over two years in treating Leeds sewage on contact beds, it was found that whether dealing with crude sewage, screened sewage, or partially settled sewage, variable but very good effluents could be obtained, much superior to those from lime precipitation. Their chemical analyses gave results which were generally well within the limit of one grain per gallon oxygen absorbed and ·1 of albuminoid ammonia; limits which have in recent years been accepted by the Lancashire and Yorkshire Rivers Boards as a provisional standard of purity for effluents going into a stream not used for drinking purposes.

In October, 1898, the Corporation established a Laboratory of its own at the Knostrop Works, and appointed to the charge of it, and general superintendence of the works,

Mr. W. H. Harrison, M.Sc. (Vic.), who is responsible for all the analytical results given from that date in this report.

The following are the average analytical results obtained over long periods, as detailed in the preceding pages:—

Table shewing the Average Analyses of the Crude Sewage and the various Filtrates from Nos. 1, 2, 3, 4, 5, and 6 Contact Beds. Purification obtained.

Grains per Gallon.	Date.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.
Crude Sewage	Oct. 27th, 1898, to Oct. 9th, 1899.	117·0	40·7	1·72	·809	8·04	—
Filtrate from Bed No. 1		75·3	11·5	1·09	·318	2·48	—
,, ,, No. 2		68·4	1·9	·318	·081	·50	·392
Percentage Purification effected by Bed No. 1		—	71 %	36 %	60 %	69 %	—
Percentage Purification effected by Beds Nos. 1 and 2		—	95 %	81 %	90 %	93 %	—
Crude Sewage	Nov., 1898, to June, 1900.	118·4	42·9	2·03	·964	8·80	—
Filtrate from Bed No. 3		82·3	12·6	·920	·289	2·07	—
,, ,, No. 4		73·0	3·3	·581	·108	·655	·261
Percentage Purification, Bed No. 3		—	70 %	54 %	70 %	76 %	—
Percentage Purification, Beds Nos. 3 and 4 ...		--	92 %	71 %	88 %	92 %	—
Crude Sewage	Mar., 1899, to Nov., 1899.	124·8	46·8	2·02	·997	9·12	—
Filtrate from Bed No. 5		81·9	13·7	1·23	·397	2·91	—
,, ,, No. 6		71·5	3·3	·666	·141	·790	·127
Percentage Purification, Bed No. 5		—	70 %	39 %	60 %	68 %	—
Percentage Purification, Beds Nos. 5 and 6 ...		—	92 %	67 %	85 %	91 %	—

These results were obtained notwithstanding the large volume and variety of trade effluents mixed with Leeds sewage. The chief difficulty occurred in connection with large quantities of iron liquor (ferrous sulphates and chlorides) coming down in this sewage, and representing as much as five tons of metallic iron per 24 hours. Generally a large part of this iron was retained by the beds, but at times, especially in summer, some of it came through in solution and afterwards settled out as a buff-coloured flocculent hydrated ferric oxide.

The final effluent evidently contained abundant dissolved oxygen, for it was found to support fish life; coarse fish, such as carp and gold fish living in the outflow basin for long periods, some of them for over 2½ years; while there was much green growth in the basin and channels. Mention may be made of Vaucheria, an alga which grows in swift flowing and therefore well aerated streams. The usual pond life was also represented in great variety in the basin, including larvæ of Chironimus, Nais, Cyclops, small worms, &c. In the body of the filter were earth worms and great numbers of Podura aquatica. These evidences of aeration are a special and valuable feature of biological effluents, which, unlike the effluents from chemical precipitation, are rarely liable to subsequent putrefaction, but on the contrary contain elements of further purification, and improve on passing to the streams.

It was found that new beds required about six weeks to get into condition, the early effluents being unsatisfactory and putrescent; but at the end of this period a rapid and permanent improvement in the filtrate took place.

The process of treatment of sewage on these contact beds was found free from nuisance, and even on digging deep into the beds which had received sewage for long periods, there was no smell but that peculiar to garden soil. It was found that stray seeds falling on the coke beds led to luxuriant growth of grass and other plants.

In these experiments analyses never shewed any important percentage of Nitrates, which, indeed, only began to appear after two months' work, and never exceeded ·6 per gallon, the average being considerably less. This was probably due to the composition of Leeds sewage which includes readily oxidisable trade effluents.

Effects of Temperature.

As bacterial action is only possible within a limited range of temperature, careful records were kept to determine if in cold weather the temperature of the beds was liable to fall below that limit.

An examination of these records shews that the temperature of the beds is determined by the sewage, and only in a very minor degree by the atmosphere. This is illustrated in the following table:—

Average Temperature of Sewage, Atmosphere, and Primary and Secondary Beds during a period of six months.

(Temperatures are in degrees F.)

Average Temperature from	Temp. of *Sewage*	Primary Bed (No. 1).					Secondary Bed (No. 2).				
		Temp. of *Atmosphere* at time of filling.	Temp. of *Bed* immediately before filling.	Temp. of *Bed* when full.	Temp. of *Filtrate*	Temp. of *Bed* when empty.	Temp. of *Atmosphere* at time of filling.	Temp. of *Bed* immediately before filling.	Temp. of *Bed* when full.	Temp. of *Filtrate*	Temp. of *Bed* when empty.
Dec. 17th to Dec. 30th, 1898	54·7	38·8	56·1	55·5	55·3	55·2	41·3	54·8	54·8	55·1	55·0
Dec. 31st to Jan. 13th, 1899	52·0	39·2	51·9	51·7	51·9	51·5	39·4	50·9	51·1	51·2	50 9
Jan. 14th to Jan. 27th, ,,	51·9	36·7	51·9	51·2	51·4	51·3	37·7	50·9	50·9	51·0	50·9
Jan. 28th to Feb. 10th, ,,	52·9	38·5	53·0	51·9	52·3	52·4	39·4	51·4	51·8	51·5	51·3
Feb. 10th to Feb. 24th, ,,	54·6	39·7	54·0	53·6	53·8	53·5	40·2	52·5	52·8	52·6	52·5
Feb. 25th to Mar. 14th, ,,	58·9	41·3	57·1	57·2	57·5	57·2	41·6	54·3	54·5	54·8	54·3
Mar. 15th to Mar. 25th, ,,	56·5	35·7	56·4	56·7	56·9	56·5	34·8	54·8	57·3	57·1	56·1
Mar. 26th to Apr. 8th, ,,	55·1	47·3	55·3	55·0	55·2	55·1	47·6	55·1	55·1	55·2	54·8
Apr. 10th to Apr. 21st, ,,	55·3	42·4	54·4	54·8	54·9	54·6	42·2	53·7	53·4	53·9	53·9
Apr. 22nd to May 6th, ,,	58·5	52·7	57·3	57·8	58·2	57·7	47·9	56·1	57·3	57·3	56·8
Average	55·0	41·2	54·7	54·5	54·7	54·5	41·2	53·4	53·8	53·9	53·6

It will be seen that in the eight hours occupied in passing through both beds the loss of temperature from the sewage to the final effluent was only $1\frac{1}{2}$ degrees. During periods of rest the heat in the beds rose to 70 and 80 degrees.

During fairly cold winters the purification effected by this process of contact filtration was not appreciably checked.

Causes of loss of capacity.

The process then was reliable to give satisfactory effluents, and the real difficulty was found to be the impossibility of maintaining the capacity of the primary beds except with such a slow rate of work, that the area of beds required would be very costly.

The loss of capacity was due to the following causes, some of which are remediable, and others not:—

1. *The passing of sand, coal dust, and road detritus into the bed.*

   These matters must be kept out, for bacterial action cannot reduce them. The sewage must be passed first through a grit tank at such speed that the heavier matters, with some of the grosser organic solids, are left behind.

2. *The degradation of the material of the filter.*

   It is found that coke, though at first carefully sorted to larger size, soon becomes broken down. No doubt this arises to a less extent with clinker, which, however, is apt to take the form of slabs, and is not very suitable for a coarse bed. Burnt ballast is very liable to reduction.

3. *The consolidation of the material of the bed.*

   As pointed out in connection with the single contact beds, Nos. 7 and 8, the loss of capacity in those cases was largely due to this cause. The material of a bed must be of very even size, or gradually the smaller

pieces, by the slight movement due to filling and emptying, tend to fit themselves in between the larger, so as to approximate to a solid mass. As we have seen, even equal sized material in course of time becomes broken down into unequal, and so consolidation takes place.

4. *More organic solids coming on to the bed than the bed can digest.*

Fibre and certain vegetable matters are very slowly dissolved, and tend to accumulate in the beds, unless the rate of working is very slow. The screening-off of some of these matters can be accomplished within reasonable cost.

5. *The presence in the sewage of matters which cannot be reduced by bacterial action*, other than the sand and road detritus which it is suggested can be settled in the grit tank.

Whether such matters exist in the sewage in an originally irreducible form, or whether such irreducible form is reached as a result of change in the bed, it is difficult to determine. But it is certain that a primary bed which has been long at work is found to contain a large quantity of matter akin to humus or garden soil, and which cannot be further reduced. The same result was found in connection with the deposit in septic tanks and the suspended solids in their effluents.

6. *The retention in the bed of mineral solids originally in solution, but which, by the oxidising action of the beds, come into suspension:* as, for instance, the iron liquors containing ferrous sulphates and chlorides, a large part of which are found to be retained in the beds, the pieces of coke being often heavily coated with red iron deposit.

It may be said that such matters should be kept out of the sewers. This is easier said than done, and it is of course to the interest of Municipalities not to put difficulties into the way of trade; and the treatment of these liquors so as to deposit the iron before they are allowed to pass into the sewers would be a costly process for which many manufacturers have not land available.

Degradation of material.

When the experiments with No. 1 Bed were stopped, the material was taken out, and that coke only replaced which could not pass through $1\frac{1}{2}$ inch mesh. This was found to only half fill the bed, so that what passed through $1\frac{1}{2}$ inch mesh and was rejected, represented half the contents of the bed. Now a reference to Page 22 will shew that a careful examination of this rejected matter gave a volume of 45·25 per cent. as made up of broken up coke. Therefore, if a material could have been used not liable to degradation, probably one-third of the loss of capacity would have been avoided. 20·39 per cent. by volume of the remainder was true deposit, but contained 70 per cent. water. It had been to some extent dried or drained by the resting of the bed, and no doubt in working conditions the deposit would contain nearly 90 per cent. of water. Every grain of matter retained by the bed holds up 9 grains of water, so that the accumulation consists largely of water held up by the spongy matter. This matter itself, as shewn by the analysis on Page 22, was to the extent of 46·6 per cent. ferric oxide and sand, and 36·5 was organic matter.

It is noteworthy that as the rough bed became choked, it became in effect a finer bed, and gave improved filtrates; but, on the other hand, it on that account more readily kept back solid matters, and towards the end the choking proceeded at a more rapid rate. If, when the capacity of the bed had fallen to 50,000 gallons, the rate of work had been reduced to one

filling a day, as was done when the capacity had fallen to 25,000, no doubt the No. 1 Bed might have gone on working verv much longer.

At this rate of work for a bed which had an area of $\frac{1}{8}$ acre, we get a possible rate of 400,000 gallons per acre of primary bed, which is probably a sanguine estimate, although that rate may safely be taken for the secondary bed. For each million gallons, therefore, $2\frac{1}{2}$ acres of primary and $2\frac{1}{2}$ acres of secondary contact beds, or 5 acres in all, would be required to deal with sewage from which only the heavier part of the suspended matter had been settled, and as far as possible the fibre, paper, and grosser solids had been screened. This large area of beds would robably be prohibitively costly. Area of bed required.

It should be noted that the fine coke bed of the first series, No. 2, which had been working for $2\frac{1}{2}$ years, had not given cause for anxiety as to the maintenance of capacity. The clinker fine beds, Nos. 4 and 6, on the other hand, were appreciably reduced in capacity, which may be due to consolidation brought about by the greater specific gravity of the clinker as compared with coke, and its greater friability.

The general conclusion, then, in reference to the early Leeds experiments with contact beds, is, that in the conditions at Leeds, and with the materials used, it was found impracticable to deal with crude sewage, not because good effluents could not be obtained, but because the capacity of the primary beds could not be maintained: and when accumulations arose, a large part of them having reached an irreducible stage, could not be consumed by resting the beds. Conclusions.

It became necessary, therefore, now to consider the best method to adopt to remove, or at least reduce, the suspended matter before dealing with the sewage on bacteria beds, or artificial filters.

Septic Tank Experiments.

The results of chemical precipitation were already known; but that process involves adding suspended matter to that already in the sewage, and so producing a very large volume of sludge. In 1897-8, attention was called to experiments with septic tanks, notably those of Mr. Cameron, at Exeter. At that time septic settlement seemed to promise, if not a complete, yet a very large consumption or digestion of the matters thrown down, and therefore the Leeds Committee proceeded to experiment on a considerable scale, and under varied conditions, to ascertain the value of septic settlement.

A complete installation was ordered designed by the Septic Tank Syndicate, of Exeter, for a couple of covered septic tanks and filters, particulars of which will follow later.

Meanwhile important experiments were started with open septic tanks.

Open Septic Tank, No. 1, 24 hour flow.

The first of these was started on February 27th, 1899. It was one of the old precipitation tanks, and had an area of 6,000 square feet, an average depth of 7 feet 7 inches, and a capacity of 250,000 gallons. Sewage absolutely crude was sent into the tank by means of seven pipes, which delivered at a depth of 3 feet below the surface. The effluent was withdrawn by means of six pipes, which drew off the liquid at a depth of 2 feet below the surface.

The flow of sewage through the tank was such that it would fill it in 24 hours, *i.e.*, the sewage was allowed to flow through the tank at such a rate that each particle might be supposed to take 24 hours for the passage.

At first an ordinary settlement of the suspended solids of the sewage took place, the effluent being in every respect similar to the effluent from the lime precipitation works. No real septic action took place in the tank until the end of April. Previous to this, only isolated and small bubbles were

evolved, and no solid matters were brought to the surface. From the end of April to the end of May, 1899, the evolution of gas became more evident, and at the same time paper, wool fibre, matches, &c., rose to the surface, and collected in large floating patches, but no fine, black sediment could be seen.

From May 30th to June 14th, 1899, in order to bring about septic conditions more rapidly, the flow was stopped, and the tank allowed to rest. During this rest it became much more actively septic. Black sooty matter rose from the bottom with a violent evolution of gas, and then spread over the surface of the tank, some of it floating and carried by the wind, formed a scum at one side of the tank. It was noticed that the colour of the liquid in the tank changed to a dark hue owing to the formation of sulphides of iron and the solution of some of the products of bacterial action. On re-starting the flow, this violent action abated within the first day, and the tank remained only moderately septic until the warmer days towards the middle of July. From July 10th to July 28th the surface of the tank was covered with a thin frothy scum, which was easily disturbed by winds. From the latter date this scum gradually became thicker until a thickness of nearly a foot was reached in September, 1899.

As more solids in suspension came out than were desired, the daily flow of sewage through the tank was reduced from August 14th to September 21st, 1899, to 125,000 gallons, in order to see if by this means the amount of solids in the effluent could be reduced. So far as could be determined in this short space of time, no alteration was produced, for on July 27th the suspended solids in the filtrate were 14·3, and on August 26th they were 14·2 grains per gallon.

On September 21st the flow was again increased to 250,000 gallons per day. From August to October, 1899, the effluent was very black, and contained a considerable amount of suspended matter. Towards the middle of October these

solids decreased considerably in amount, and continued so until November, when the effluent again became black and turbid. From November 9th to November 13th the effluent was clear, but became turbid again on the 20th. These fluctuations of solids have continually occurred since then. No reason for these changes could be noticed, the evolution of gas being no greater when these flushes occurred.

Towards the middle of December, 1899, the scum became much thinner, owing, no doubt, to the advent of cold weather. During the sharp frost from February 2nd to February 15th, 1900, this scum was frozen so hard at the outlet end of the tank as to easily bear the weight of a person walking upon it. Upon several occasions this frozen scum was raised up into a dome by the accumulation of gas beneath it. As the frost did not penetrate deeper than this scum, it would appear that this surface layer is a bad conductor of heat, and so to some extent would help to conserve the heat of the sewage during cold weather. During the month of February, 1900, the average amount of heat lost by the passage of the sewage through this tank was only 1·6° F. Since this last period of frost the scum became much thinner, and not so coherent.

Analyses of the effluent shew that the amount of suspended solids in the effluent became greater the longer the tank was worked:—

March to June, 1899 =	9·1 grains per gall.,	suspended solids.
July to October, „ =	11·0	„	„
Nov., 1899, to Feb., 1900 =	15·2	„	„
March to June, „ =	15·2	„	„

This points to the necessity of frequently withdrawing a portion of the sludge for the purpose of maintaining a fairly constant capacity in the tank. If the flow had originally been regulated to fill the tank in 24 hours, so that particles should take 24 hours for their passage through it; and if now, after 16 months working the tank was half full of sludge, then evidently the water capacity was reduced to half, and the flow was really a 12 hours' and no longer a 24 hours' flow.

The experiment continued under the same conditions until the end of 1900, when soundings shewed the tank to be very full of sludge, and the suspended matter coming out in the effluent was larger than the filters could deal with.

The tank was therefore cleaned out, and, in doing so, the following attempt was made to estimate the amount of sludge that had been consumed. After the top water was removed the volume of sludge was measured, and found, on experiment, to average 82·18 % of water, and to represent 143·92 tons of dry matter. From the following table (see Page 42) it will be seen that over the whole period the sewage going into the tank had contained on average 42·3 grains per gallon of suspended matter, and, deducting from this the average of what had gone out with the effluent (see Page 42), viz., 13·6 grains, it follows that an average 28·7 grains per gallon had been left behind in the tank—multiplying these figures by the total volume in gallons treated during the whole period we get the following figures :—

Total dry solids in the sewage going into the tank	362·10	Tons
„ „ „ going out with the effluent	116·40	„
Dry solids left in the tank	245·70	„
Estimated amount of dry solids found in the tank, December, 1900 (as above)...	143·92	„
Amount of matter digested	101·78	„

This represents 41·4% of the dry solids left in the tank, and 28·1% of those originally in the sewage.

Average of all Analyses from February 27th, 1899, to Decemrer 10th, 1900.

Grains per Gallon.	Suspended Solids.	Soluble Solids.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.
Crude Sewage	42·3	74·9	2·24	1·017	9·07
Septic Tank Effluent (No. 1 ...	13·7	63·2	1·87	·446	4·42
Percentage Purification	67·6%	15·6%	16·5%	56·1%	51·2%

Purification Effected.

Table shewing Suspended Matter in Grains per Gallon in the Sewage and in the Septic Tank Effluent, from Analyses made on the given dates.

Date.	Suspended Solids in Crude Sewage (Grains per Gallon).	Date.	Suspended Solids in No. 1 Septic Tank Effluent (Grs. per Gall.)
Mar. 22nd, 1899	48·3	Mar. 13th, 1899	11·9
April 5th, ,, ...	36·5	April 5th, ,, ...	2·9
,, 19th, ,, ...	37·6	,, 17th, ,, ...	6·6
May 4th, ,, ...	35·7	May 4th, ,, ...	15·3
June 1st, ,, ...	42·5	July 13th, ,, ...	6·9
July 14th, ,, ...	39·3	,, 27th, ,, ...	14·3
,, 26th, ,, ...	46·0	Aug. 26th, ,, ...	14·2
Aug. 28th, ,, ...	58·8	Sept. 26th, ,, ...	15·4
Oct. 3rd, ,, ...	41·8	Oct. 12th, ,, ...	4·4
,, 24th, ,, ...	69·5	Nov. 12th, ,, ...	28·2
Nov. 16th, ,, ...	59·5	,, 29th, ,, ...	15·1
Dec. 14th, ,, ...	35·5	Dec. 26th, ,, ...	12·8
Jan. 9th, 1900	50·6	Jan. 30th, 1900	12·5
Feb. 13th, ,, ...	40·0	Feb. 22nd, ,, ...	7·6
Mar. 6th, ,, ...	36·6	Mar. 5th, ,, ...	12·3
,, 21st, ,, ...	25·9	,, 15th, ,, ...	8·1
April 30th, ,, ...	50·5	,, 24th, ,, ...	16·4
May 28th, ,, ...	44·9	Apr. 2nd, ,, ...	17·8
June 25th, ,, ...	33·5	,, 24th, ,, ...	18·5
Sept. 12th, ,, ...	37·6	May 7th, ,, ...	21·7
Oct. 30th, ,, ...	30·9	June 11th, ,, ...	15·3
Nov. 29th, ,, ...	31·2	Sept. 12th, ,, ...	14·0
		Oct. 30th, ,, ...	19·8
		Nov. 29th, ,, ...	15·1
Average	42·3	Average	13·6

The Table shews the occasional flushes of suspended matter in the effluent to be independent of the quantity in the sewage.

This tank, after being cleaned out, was re-started and worked continuously at the 24 rate (such flow as would fill the tank in 24 hours) for two years, from January 8th, 1901, to January 15th, 1903.

It is interesting to note that, whereas in the first experiment the tank had taken four months to reach full septic condition, now at the end of a fortnight gas bubbles began to rise, and within a couple of months the whole surface was scummed over, and the effluent was of septic colour and condition. This was due to some of the old sludge having been left in the tank for purposes of inoculation.

The same variations in the quantity of suspended matter coming away with the effluent liquor took place as were shown in the table already given in connection with the first experiment, and the average gradually rose as the tank accumulated sludge.

The following is the average of the two years' analyses in grains per gallon :—

Grains per Gallon.	Soluble Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.
Crude Sewage	77·1	42·5	2·88	·741	8·07
Effluent Liquor	63·1	15·2	1·85	·385	4·52
Percentage Purification	18·1%	64·2%	35·7%	48·0%	43·9%

An estimate of the digestion by the septic action in the tank, carried out on the lines already explained at p. 41 *ante*, showed a digestion of 61% of the sludge left in the tank, and 39·4% of the suspended matter originally in the sewage. These rates are considerably higher than those of the former estimation, probably because they are based on analyses of crude sewage, while the sewage going into the tank at this period was liable to sedimentation in the channels.

This septic tank No. 1 was re-started in 1903, and has been working on similar lines up to the end of 1904.

Septic Tank No. 2, 48 hours' rate.

The second open septic tank experimented with also had a capacity of 250,000 gallons.

The tank was first filled with crude sewage on April 28th, 1899, when a current of sewage equal to 125,000 gallons per day was sent through the tank. On May 12th this was increased to 250,000 gallons per day, which would fill the tank in 24 hours.

From the beginning of May until the middle of June, 1899, the septic action was very feeble, but towards the end of June matters were thrown up from the bottom, and on July 11th had accumulated to such an extent that half the surface of the tank was covered with a thick brown scum. On July 17th this thick scum had given place to a thinner but more uniform scum, which covered the whole of the surface, whilst bubbles of gas and black sooty matter were continually breaking through it. From this point the scum gradually thickened until at the end of July it had reached a thickness of 5-6 inches.

On October 30th, 1899, 6 square yards of the scum were removed experimentally. The matter removed was quite spadeable, and was in a condition to be at once carted away. When dried it was found very full of fibre. By November 4th a new scum was beginning to form on this cleared space, and by November 22nd it was as thick as the scum covering the rest of the tank.

As it was desired to see the effect of a slower flow through a septic tank, the flow was reduced in December, 1899, to 125,000 gallons a day, which would fill the tank in 48 hours, so that each particle may be supposed to take 48 hours to pass through. This rate of flow was continued for 12 months,

and analyses made upon this effluent have shewn that this reduction of flow has had very little effect upon the quality of the effluent produced.

The working of this tank, and the analyses of the effluents, are very similar to those obtained with tank No. 1, and need not therefore be given in detail. It was emptied and restarted in December, 1900, the septic development being hastened by leaving some of the old septic sludge to inoculate the new deposit, and by allowing sewage to stagnate in the tank for a week at starting. After working about a year the periodical flushes of suspended matter in the effluent appeared which were referred to in connection with septic tank No. 1 (see the table page 42). In this case they seemed to coincide with heavy rain at a time when there was a thick dry scum on the surface. The rain caused the scum to sink lower, and so disturbed from the underside matter which, sinking, passed to some extent through the outflow channels.

The tank was again emptied and restarted in January, 1903, this time at the 24-hour flow, no material advantage having been found in the slower flow.

Septic Tank No. 3, 12 hours' rate.

Septic Tank No. 3 also was one of the old precipitation tanks, and had a capacity of 250,000 gallons. It was first started in May, 1899, and was in full septic condition by September.

As the experiment with No. 1 tank had been at the 24-hour rate, and that of the No. 2 tank at the 48 hours, the third tank was worked at a 12-hour rate—that is, at a rate of flow double that tried with No. 1 tank. The effluent was unsatisfactory, containing too much suspended matter for the filters to be able to deal with—and this speed of flow being considered impracticable the experiment was stopped, the tank emptied and restarted in December, 1900, at a very slow speed, which would fill the tank in 72 hours. It was worked at

72 hours' rate.

this rate during the whole of 1901 and 1902. It was remarkable that no real scum was formed, only patches of black froth, which were easily dispersed by the wind.

The effluent was very black, and if the following analytical results be compared with those of No. 1 tank, which was worked at the 24-hour rate, it will be seen that they are certainly better, especially as regards the amount of suspended matter in the effluent. The benefit, however, would be more than balanced by the triple area of tanks required for a slow flow at the 72-hour rate.

Average of all Analyses from December 8th, 1900, to January 5th, 1903.

Grains per Gallon.	Soluble Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.
Crude Sewage	77·1	42·5	2·88	·741	8·07
Effluent from No. 3 Tank	64·0	9·9	1·79	·343	3·59
Purification effected...	16·9%	76·7%	37·8%	53·7%	55·5%

An estimate of the sludge digestion in this experiment gave, as a result, a much smaller percentage than at the 24-hour speed, a result quite contrary to expectation.

It may be that in the channel which fed the crude sewage to the septic tanks, Nos. 1, 2 and 3, there was some selective action as to suspended matter owing to the relative positions of the tanks and their different speed of flow.

Estimate of Sludge Digestion.

In order to obtain, if possible, more correct data as to sludge digestion, the three tanks, Nos. 1, 2 and 3, have during the whole of 1903 and 1904, been worked from the same flow of crude sewage at the same 24-hour rate for each, with the intention of getting a joint estimation based on the combined data.

In order to eliminate errors which may have previously arisen in these necessarily somewhat approximate calculations, samples

of sewage and effluent were now drawn every hour both day and night throughout the whole period, and these were averaged every 24 hours.

Average of the Analyses made from January 15th, 1903, to December 18th, 1904.

Grains per Gallon.	Solids in Solution.	Solids in Suspension.	Free Ammonia	Alb. Ammonia	Oxygen Absorbed.
Sewage sent into Tanks	66·3	33·2	1·62	·434	5·79
Effluent from the Tanks	62·6	12·7	·926	.303	4·18
Percentage Purification on Crude Sewage	12·4%	70·0%	39·0%	40·7%	44·9%

At the close of the period there was found in the three tanks a volume of sludge, representing 299·4 tons of dry solid matter, adding to this 1·49 tons of dry solid matter in the scum that had been removed in the course of the year, we get 300·89 tons of undigested dry solids—from which must be deducted 15·3 tons, the dry solid matter contained in the septic sludge left in the tank for inoculation at the beginning of the year—which leaves 285·59 tons as the net amount.

The total volume of the sewage dealt with in the three tanks during the two years was 470,300,000 gallons, containing an average on the whole two years of 33·2 grains suspended matter per gallon. Multiplying these two figures together we get 995·9 tons as the dry solid matter brought to the tanks by the sewage Now the effluent carried away on average 12·7 grains of suspended matter per gallon, or 381 tons dry solids for the whole volume and period dealt with. Deducting 381 tons from the 996 tons, we get 615 tons as the amount left behind in the three tanks. We have already noted that the scum which had been removed and the sludge left in the three tanks at the end of the year contained 285·59 tons of dry solid matter. If finally, we deduct this last figure from the 615 tons left in the tanks,

615—286 = 329 tons, which is the amount digested by septic action in the tanks. This is 33% of what was originally in the sewage, and 53% of what was left in the tanks.

In other words, septic tanks working at the 24 hours rate with crude Leeds sewage, digested one-third of the suspended matter originally in the sewage.

Again the sewage dealt with during the whole period contained 996 tons of dry solid matter—

Of this the effluent carried away	38%	or 381 tons.
There remained in the tanks at the end of the period, mostly in indigestible form to be removed	29%	or 286 „
Sludge digested (reckoned as dry solid matter)	33%	or 329 „
	100%	996 „

So far the experiments with septic tanks referred to sludge digestion, and the effect of varying rates of flow on the quality of the effluents. Experiments were now undertaken in another direction. As evidently there is only partial digestion of the matter remaining in the septic tank, and as from time to time the accumulations will have to be removed, this consideration limits the size of the tank, and the question arises: if for a considerable volume of sewage, a number of tanks are required, will it be better to work each independently, or to work them all or some of them in series?

Tanks in Series.

An experiment on a large scale was therefore started in June, 1899, with four of the new precipitation tanks, which were used as septic tanks, in series.

Their collective capacity was 2,000,000 gallons, and the flow of sewage was regulated at 2,000,000 gallons per 24 hours, the whole flow passing through the first tank, and in

succession through the series. The sewage was taken from Nos. 1 and 2 precipitation tanks, so that all the grit and some of the grosser solids were there first settled.

It was anticipated that working in series the greater part of the sludge would be retained by the earlier tanks, and that the effluent passing from the last tank would be more free from solids in suspension than the effluent from tanks acting independently. Work was started on June 12th, 1899, and before two months were completed the experiment was necessarily stopped on August 4th, because the first tank of the series was absolutely choked with very heavy sludge, some of it rising in islands above the water level, leaving channels through which the sewage flowed forward to the other tanks. No septic action had arisen in the first tank, though a few bubbles began to rise in the others.

The flow being at a rate to fill the whole series of four tanks in 24 hours, the flow through the first was at four times that rate, and the settlement was so rapid that the first tank became full before even septic conditions had arisen. As it was inconvenient at the time to deal with so large a volume of sludge, the tank was not emptied, but was left stagnating until it would be possible to remove it. At the end of a month it was found that the accumulations had become levelled, that a scum had formed, and that a slow septic action had developed. The experiment was then tried of allowing a small flow from one of the active septic tanks to go into this choked tank, to see if septic action could be hastened, and the accumulation could to any extent be digested. As a result, very active fermentation took place, with violent evolutions of gas, and a thick scum was formed.

After a fortnight this septic flow was replaced by a small flow of sewage of 50,000 gallons a day. The resultant effluent was very offensive, in fact worse than Leeds sewage, the thick deposit became thinner, a very active evolution of gas

continued, and, no doubt, as the sludge became thinner, much of it passed away in the effluent to the other tanks. After a month the flow of sewage at the 24 hours' rate was resumed, and nothing was removed from either the first choked tank or the later ones for a considerable period.

Thus in a new set of tanks, where, as we know, septic conditions cannot arise fully for some months, the first tank was rapidly choked ; but when septic action had fully developed, it is very interesting to note that the work went on for 12 months before it became necessary to clear out the first tank —which, however, by that time had a very thick scum and much bottom sludge. The later tanks of the series receiving only the lighter suspended matters, accumulated thin sludge and very slowly, so that they were able to run for three years before any removal became necessary. The second and third tanks of the series had but thin scums, while that on the fourth tank was very thin indeed, and after 12 months had only spread over a small part of the tank.

Some advantage was therefore found by working the tanks in series, that the heavier sludge was limited to the first tank, which could be more conveniently emptied, while the later tanks only required any removal of sludge at much greater intervals. On the other hand, the expectation that the effluent from the last tank would be more free from suspended matter than the effluent from tanks worked independently, was not fulfilled.

At first, no doubt, there was less suspended matter in the effluent, but as soon as the last tank had accumulated some sludge and full septic action had set in, the constant movement of the matter from the bottom to the top and back again caused the average amount of suspended matter to pass out in the outflow channels.

The analyses did not materially differ from those of tanks worked independently.

The following was an interesting and quite novel experiment. Sir Wm. Ramsay, a member of the Royal Commission, having called attention to the activity of septic tanks he had noticed at Bombay in a hot climate, the question arose how far it might be worth while to heat the sewage going into the tanks. It was thought likely that this would lead to such greater bacterial activity that a smaller area of tanks would be necessary—that is, that a more rapid rate of flow would be possible, and that the digestion of the settled matter would be much greater.

Heated Septic Tanks.

Four small tanks were specially built all of the same dimensions, and having a capacity of 5,837 gallons. The sewage used was finely screened, and was delivered into the tanks in such a manner that no selective action occurred, each tank getting the same strength of sewage as was sent into the others.

The sewage sent into the first tank was not heated, and that sent into the others was heated to 70° F., 85° F. and 100° F. respectively, by means of the injection of steam.

The experiment was started on April 24th, 1903, and continued until May 16th, 1904.

Nothing more than a thin frothy scum was ever noticed on any of the tanks, and in every respect they behaved as ordinary septic tanks.

The following table gives the average of all analyses made from April, 1903, to May, 1904, and also the Percentage Purification brought about in each tank :—

Test.	Effluent from Tank at Normal Temperature		Effluent from Tank at 70° F.		Effluent from Tank at 85° F.		Effluent from Tank at 100° F.		Sewage
	Analysis	Percentage Purification	Analysis	Percentage Purification	Analysis	Percentage Purification	Analysis	Percentage Purification	Analysis
Free NH_3	·928	41·2 %	·920	41·0 %	·913	41·4 %	·894	42·7 %	1·56
Alb. NH_3	·287	33·7 %	·251	42·4 %	·255	41·5 %	·251	42·4 %	·436
Oxygen absorbed ...	3·72	47·6 %	3·69	48·0 %	3·61	49·1 %	3·51	50·5 %	7·09
Soluble Solids ...	63·5	7·0 %	61·6	9·8 %	61·7	9·6 %	60·8	10·9 %	68·3
Suspended Solids ...	10·5	71·2 %	10·8	69·6 %	9·4	74·2 %	8·6	76·4 %	36·5

An estimate of the sludge digestion did not show any increase of digestion in the heated tanks, the digestion in the normal tank being indeed the higher, and it would seem that under normal conditions at the 24 hours flow, all is digested that is capable of digestion.

The above analyses shew rather better results from the heated tanks, but scarcely such as would warrant the cost of heating.

On the other hand, there is no doubt that septic action is more active in summer than in winter, as the following experiment will show.

Small Experimental Septic Tank.

This was a small experiment started on December 28th, 1900, with an iron tank, oblong in shape, 4 feet in depth, and holding 1,000 gallons. A flow of sewage equal to a 24-hours' flow was adopted and continued throughout the experiment, which lasted until November 11th, 1901.

The object of the experiment was to measure the rate of gas production, to discover if possible the determining factors, and only incidentally to measure the amount of sludge digestion and the purification effected.

In order to measure the gas given off, a large funnel, having an area of 207 square inches, was supported in the centre of the tank just below the surface, so that any gas rising within the area of the funnel mouth would be collected and concentrated within the delivery tube. From this the gas was conducted into a graduated glass cylinder filled with water which the gas displaced. Periodically, after equalizing the pressure within the tube to that of the air, the volume was read.

Various other facts connected with the changing physical conditions of the experiment were collected and tabulated daily.

The tank was not septic until the middle of May, 1901, and even then only about 200 c.c. of gas were collected daily. However, from this date a rapid acceleration took place, culminating towards the end of August, 1901, when the largest amounts of gas were collected. From this date a gradual decrease occurred.

The following shows the average daily production for each week from May-November, 1901 :—

Week Ending	Average Daily Production of Gas.	Week Ending	Average Daily Production of Gas.
May 25th, 1901	286 c.c.	Aug. 24th, 1901	28104 c.c.
June 1st, ,,	524 ,,	,, 31st, ,,	37231 ,,
,, 8th, ,,	741 ,,	Sept. 7th, ,,	26094 ,,
,, 15th, ,,	1973 ,,	,, 14th, ,,	19824 ,,
,, 22nd, ,,	3465 ,,	,, 21st, ,,	21122 ,,
,, 29th, ,,	5984 ,,	,, 28th, ,,	22804 ,,
July 6th, ,,	8754 ,,	Oct. 5th, ,,	27413 ,,
,, 13th, ,,	14513 ,,	,, 12th, ,,	19264 ,,
,, 20th, ,,	23670 ,,	,, 19th, ,,	19325 ,,
,, 27th, ,,	23327 ,,	,, 26th, ,,	17897 ,,
Aug. 3rd, ,,	26030 ,,	Nov. 2nd, ,,	17297 ,,
,, 10th, ,,	25064 ,,	,, 9th, ,,	13437 ,,
,, 17th, ,,	24568 ,,		

The total amount of gas collected was 2,869 litres, from a funnel area of 207 square inches, and as the area of the tank was 40 square feet, or 5,760 square inches, therefore the total amount of gas evolved by this tank was ... **79,830 litres.**

This gives for the period from May 1st to November 11th, a total of 187 days, after deducting stoppages, an average daily production of gas of ... ... **427 litres.**

The daily amount of sewage treated was 1,000 gallons, so that *every 100 gallons of sewage treated in this tank evolved on the average* **42·7 litres of gas,** or 1·5 cub. feet per day.

As no gas was collected during the winter months, and as the rate of evolution is then much decreased, the actual average for a whole year would be more nearly 1 cub. foot of gas for every 100 gallons of sewage treated.

From the records kept of the temperature of the sewage and the atmosphere, it appears that the rate of gas-production follows the temperature of the sewage, and incidentally that of the atmosphere.

The variations in barometric pressure do not seem to have any effect upon the rate of gas-production.

AVERAGES OF ALL ANALYSES FROM DECEMBER 28TH, 1900, to November 11th, 1901.

GRAINS PER GALLON.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed	Soluble Solids.	Suspended Solids.
Crude Sewage	2·34	·787	8·45	77·1	38·0
Effluent from Experimental Septic Tank	1·60	·379	4·41	62·1	15·6
Purification effected	31·6 %	51·8 %	47·8 %	19·5 %	58·9 %

An estimate of the sludge digestion in this case gave only 17·9 % digestion of the suspended matter in the sewage.

All the experiments hitherto described were with open septic tanks, and it is necessary now to give an account of the trial of closed septic tanks, in order to note what advantages, if any, they have over those that are open.

Closed Septic Tanks

The closed septic tanks, constructed upon designs submitted by the Septic Tank Syndicate, of Exeter, consisted of two rectangular tanks, 54 feet long by 10 feet broad, and a depth of 9 feet at the deepest point. Both were covered in by brick-work arches. The mean water level in the tanks was about 6 feet 6 inches from the bottom of the tank. These two

tanks together treated 40,000 gallons of crude sewage per day. On June 6th, 1899, they were filled with sewage from which the grit had been settled, and were allowed to stand full until June 9th, when a continuous current of 40,000 gallons per day of sewage was sent through them at the 24 hours' rate.

By June 18th septic conditions had developed, the effluent being dark in colour, whilst a large number of small bubbles were continuously arising from the liquid in the tank. The surface was covered with a thin frothy scum. These conditions became more and more developed until a maximum was obtained on August 16th, 1899, and the surface became covered with a very thick layer of fibre, &c. This surface layer was similar in composition to that on the open tanks, but very light brown in colour.

Average of Analyses referring to the Closed Septic Tanks for the First Year's Working.

Grains per Gallon.	Total Solids.	Suspended Solids.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed (4 hrs., 80°F.).
Crude Sewage	120·2	45·4	2·34	1·13	9·64
Effluent from Closed Septic Tank	77·9	12·8	1·87	·437	4 82
Purification effected	—	71 %	20 %	61 %	50 %

From July, 1900, onwards, the tank behaved in a very similar manner to the Open Septic Tanks with regard to the effluent, which generally was about the strength of that obtained from the open tanks. Flushes of solids were also noticed, and these were also coincident with a decrease in thickness of the scum. For instance, during March and May, 1901, the scum became very thin, and during the same time heavy flushes occurred.

The scum throughout had a very pale colour upon the surface, probably due to presence of light, but beneath it was quite black from the presence of sulphide of iron.

On August 12th, 1901, after two years' working, the tank was cleaned out.

AVERAGE OF ANALYSES FOR THE WHOLE PERIOD OF WORKING.

GRAINS PER GALLON.	Total Solids.	Suspended Solids.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed. (4 hrs., 80° F.).
Crude Sewage	115·4	41·0	2·31	·957	8·87
Effluent from Closed Septic Tank	76·2	12·7	1·88	·406	4·63
Purification effected	—	69·0 %	18·6 %	57·5 %	48·9 %

The estimate of sludge digestion for the first two years gave 31·5 % digestion of the suspended matters originally in the sewage.

After emptying, the closed septic tanks were restarted for a second period in August, 1901, some septic sludge being left for inoculation.

Only a very thin scum formed during 1901 and 1902, and even this during the later period disappeared, the surface of the tank being quite free. Towards the middle of 1904 heavy flushes of solids occurred, due to the large amount of sludge in the tank, and these continued at intervals until the tank was cleaned out on January 11th, 1905.

The following are the analytical results up to May, 1904, from August, 1901, after which date no analyses were made :—

GRAINS PER GALLON.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Suspended Solids.	Soluble Solids.
Crude Sewage	2·05	·607	7·72	44·0	74·3
Closed Septic Tank Effluent ...	1·41	·326	3·63	10·4	60·6
Percentage Purification	31·2 %	46·3 %	52·9 %	76·3 %	18·4 %

The sludge digestion for the second period worked out at 37·2 %, which is no doubt above the mark, as no analyses were taken after June, 1904, and in the last six months there were flushes of suspended matter which would have materially reduced the figure, probably to the 31 % which was obtained for the first period.

General Observations on the Septic Tank Experiments.

A septic tank differs from an ordinary settling tank only in the speed of flow. In the latter case the flow is fairly rapid, such for instance as would fill the tank in three or four hours—and so much solid matter settles down that the tank is full and requires emptying before septic conditions have arisen. Where the flow is a slow one, say such as would fill the tank in 24 hours, the septic conditions arise long before the accumulations have risen high in the tank.

Maturing of Septic Tanks.

When a septic tank is first started, a simple deposition of the suspended matters occurs, the effluent obtained being in reality only settled sewage. Soon, however, a fermentation of the deposited solids takes place, and a large volume of gaseous products is evolved. The period elapsing between the starting of the tanks, and the occurrence of the phenomenon, varies with the state of the weather, being shortest in Summer.

With an entirely new tank, several months elapse before septic conditions are fully developed, but where some septic sludge has been left in or been put in, bubbles of gas begin to ascend in a few days, and the full septic condition is reached much earlier. Allowing sewage to stagnate in a new tank has the same hastening effect.

In time the evolution of gas increases, bringing black matter up to the surface, where the bubbles burst and release most of the matter, which falls again to the bottom. Occasionally the fermentation in the bottom sludge accumulates there a large quantity of gas, which raises to the surface considerable masses of black mud. Some of these matters—still supported on the surface by bubbles—are dried by the sun and wind, become attached to light floating matters such as fibre, matches, &c., and, driven by the wind, begin to accumulate in a corner of the tank. They tend to form a compact mass, which spreads

gradually over the tank. Other matters are brought up underneath and supported by gas, which only finds a vent here and there. So gradually a scum is formed a foot or more in thickness. During the winter months, and especially immediately after periods of severe frost, and also during periods of heavy rainfall, this surface layer shews a decided tendency to become thinner.

Whilst these changes have been taking place in the contents of the tank, the character of the effluent obtained has also altered. At first the outflow has all the characteristics of settled sewage, and at Leeds is yellow in colour owing to the presence of iron. As the putrefaction of the sediment in the tank proceeds, the effluent becomes darker coloured and almost black from the production of sulphides of iron, and somewhat offensive owing to the solution of some of the products of bacterial action.

The gases evolved by septic action are for the most part inodourous, consisting mainly of methane; and it has been suggested to use them for heating and lighting by covering the tanks, and so storing the gases.

Covering Septic Tanks.

The question whether septic tanks should be closed or not, is of importance in view of the extra cost of roofing them in. The advantages claimed for closed tanks are:—

1. That the roofing excludes the air from the surface and promotes better anærobic conditions.

2. That the resultant gases are under control, and can be utilised for lighting or heating.

3. That evil odours are prevented from escaping.

4. That the heat of the sewage is better maintained.

The experience of Leeds shews that whatever results were obtained from the closed septic tanks were equally well obtained by the open, and that the scum which forms on septic tanks, itself soon gives a cheap automatic roof, which

is chiefly of value in preserving the heat in the sewage, the floating layer being a bad conductor. If the scum is removed the septic action is not checked.

The average loss of heat of the sewage in passing through the open septic tanks was 1·6° F., while through the closed it was 0·8° F., and the difference is too small to warrant the expense of a roof on this account.

There is some heating value in the gases, but the roofed-in septic tanks are really gas holders, and except under proper care, may become a serious source of danger.

In the open septic tanks, the gases produced are at once dispersed. For the most part they are inodourous, no appreciable nuisance having arisen at Leeds, though the effluent itself is more or less offensive. Leeds sewage is diluted and mixed with trade effluents, and no doubt where strong domestic sewage is being treated, greater nuisance may arise, but the roofing cannot permanently confine the gases produced. In the neighbourhood of dwellings the roofing over may be useful for æsthetic reasons.

In appearance the effluents obtained from the open and closed scptic tanks were identical, whilst from a chemical point of view the difference is small, but so far as it goes is in favour of the closed tanks.

Average of all Analyses of Nos. 1, 2 and 3 *Open Septic Tanks*, and also of *Closed Septic Tanks*, from October, 1899, to May, 1904:— Analytical Results from Open and Closed Tanks.

Grains per Gallon.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Solids.	
				Soluble	Suspended
Effluent from CLOSED Septic Tank	1·59	·356	4·01	61·7	11·2
Effluent from OPEN Septic Tank	1·58	·377	4·27	62·5	13·6

The putrefactive fermentation which takes place in the tanks is due to the presence of immense numbers of anaërobic bacteria, and brings about a change of the organic suspended matter into gaseous and liquid products, which has been referred to as digestion. The early belief, that all suspended matter would be so digested, has not been fulfilled at Leeds or elsewhere. From the data given in the previous experiments, and especially those with heated sewage, it appears that the larger part of the suspended matter—at all events in Leeds sewage—soon reaches a condition which is not further reducible by bacterial action—becomes, in fact, earth or humus. Nevertheless the digestion in the septic tank is, so far as it goes, very valuable. Various estimations of the proportion of suspended matter digested have been given in the previous pages, the most reliable of which gives 33 %, that is, a digestion of one-third of the suspended matter originally in the sewage. As some of the estimations were considerably below this proportion, it does not seem safe for Leeds sewage to put it at above 30 %.

Sludge Digestion.

Comparative Sludge Production by Different Processes.

The amount of sludge produced by septic tanks is, therefore, less than that of natural settlement, and much less than that from chemical precipitation.

It must not be forgotten, however, that in the case of septic tanks much suspended matter goes off in the effluent, and has to be dealt with elsewhere.

Let us attempt a comparison of sludge production by the three processes.

Leeds sewage contains suspended matter which varies in quantity from hour to hour within wide limits. Take it to be on the average of a year 42 grains per gallon. (See the table p. 42).

In chemical precipitation it would be necessary to add about 10 grains per gallon of lime to attain good results, and this might leave three grains of solids per gallon in the effluent.

Although some of the products of the re-action may go into solution, the sludge production may be taken as 42 + 10 = 52 — 3 = 49 grains per gallons.

In flowing natural settlement with a fair area of tank, results could be obtained leaving about 10 grains in the effluent. The sludge production would be 42 — 10 = 32 grains per gallon.

Stagnant natural settlement gives better results, leaving, say, some six grains, and the sludge would be 42 — 6 = 36 grains per gallon.

Septic settlement at Leeds left an average of 13 grains in the effluent (see the table on page 42), and we may take the digestion as 30% of the matter originally in the sewage. First deduct the 13 grains going off with the effluent from the 42 grains in the sewage, which leaves 29 grains as left behind in the tank. Now of this, 30% of 42, or 12·6 grains are digested; and 29 — 12·6 gives us 16·4 grains per gallon on the sludge production.

The following table summarises the position :—

Grains per Gallon.	Sludge.	Effluent.
Chemical precipitation	49	3
Stagnant Natural Settlement ...	36	6
Flowing ,, ,, ...	32	10
Septic Settlement	16	13

Septic settlement in these conditions would produce only one-third the sludge which results from effective chemical precipitation, and one half that of unassisted flowing settlement.

The second column, however, must also be kept in view, for the speed of filtration and the life of the filters are greater in inverse proportion to the suspended matter in the effluent coming to them.

The choice of what is best must, therefore, not depend entirely on the question of sludge production, but on other considerations, which will be referred to later on.

Character of Septic Tank Sludge.

Now it is important in passing to note that septic sludge and the sludge from chemical precipitation and natural settlement are different.

In septic sludge, putrefactive change has, in regard to a large part of it, taken place and been completed, while in regard to the remainder it is proceeding. In the other sludges as they are at first removed from the tanks, putrefaction has scarcely begun. It was anticipated that the emptying of septic tank sludge would give rise to a great nuisance, and for that reason that it would be difficult to deal with it. In practice at Leeds it was found to give rise to very little smell, and such as there was soon passed away. Further, in drying it, the water more readily drains away than it does in the other sludges, and the density of the septic sludge is greater than that of the other sludges.

Thus, at Leeds, septic sludge usually contained 82 to 85 per cent. water, while the other sludges contained 90 per cent. of water. When it is remembered that 80 per cent. sludge contains half the water and occupies half the room of 90 per cent. sludge, it will be seen that the point is of some importance. If, however, it should be required to press the sludge into cake, septic sludge offers considerable difficulty.

If septic tanks are only emptied at long intervals, the bottom sludge is apt to be so dense, that it will not flow in the pipes without stirring and diluting.

It is necessary to add that although the gases arising from the septic tanks are for the most part inodourous (at Leeds an area of over two acres of such tanks give rise to no appreciable nuisance), and although the septic sludge proved very much less offensive than had been expected, the septic effluent, on the

other hand, is apt to smell when disturbed, as it must be in distributing, and still more in spraying it on filter beds, because of sulphur and other compounds which it holds in solution.

Comparison of Crude and Septicised Sludge.

An analysis of the sludge in No. 1 open septic tank showed a loss on ignition of 43·4 per cent., leaving an ash of 56·6 per cent. Of this ash 26 per cent. was ferric oxide, 50 per cent. sand and insoluble matter, and the remainder phosphates, sulphates, etc.

An analysis of the suspended matter as brought down by the sewage gave 51·9 per cent. loss on ignition, leaving 48·1 per cent. ash, of which 29 per cent. was ferric oxide and 35 per cent. sand and insoluble matter.

It will be noticed that the septic action brought about a reduction in the proportion of the organic matter and an increase in that of mineral matter.

Emptying of Septic Tanks.

From time to time septic tanks will have to be emptied. At Leeds the longest time which it was found practicable to let them go was two years, except the later tanks of those worked in series.

The accumulation of sludge means a reduction of capacity; and a flow originally set at the 24 hour rate for a new-started tank, becomes a 12-hour flow when it is half full of sludge—and, therefore, as time goes on, a septic tank gradually sends out more and more suspended matter with the effluent. It is this condition that compels the emptying of the tank, rather than the bulk of the accumulations.

It would be important to so construct septic tanks, that at frequent intervals—monthly, weekly, or even daily—valves connected with different parts of the tank bottom would be opened and a small quantity of sludge withdrawn. If the withdrawal were from the bottom, and the valves were only opened for a very short time, the outflow might probably be limited to the

densest sludge, and to that of which the putrefaction is the most complete. In this way a permanent capacity could be maintained, and the rise in the quantity of suspended matter in the outflow prevented.

Suspended Matter in Septic Tank Effluent.

The large quantity of suspended matter coming out with the effluent is one of the difficulties which the use of septic settlement gives rise to. Matter is constantly on the move in septic tanks. Bubbles rise like little balloons, carrying up with them small particles of matter—which, when the bubble bursts, descend again to the bottom. Several unsuccessful experiments were made in screening the effluent, but the particles are very finely divided and difficult to arrest, while a very thin surface of them blocks the screen and soon stops the flow. It was attempted to pass the effluent before filtration through an additional tank for the settlement of these matters, but they are very light and settle but slowly, and, as soon as they do, the septic action goes on, and the movement up and down recommences in front of the outflow passages.

Tanks in Series.

In the experiment of septic tanks in series (p. 48), which was undertaken partly to obtain a clearer effluent, no advantage in this direction was found by using the tanks in succession. But there may be convenience in using the tanks in series, because the heavier matters and the thicker scum will be found in the first of the tanks, which can be more easily and frequently cleaned out, the later tanks going on to several years. At Leeds four tanks were used in series ; but the accumulations in the first tank would be more rapid with a longer series, or if the first tank were relatively smaller. If the flow is at the 24 hours' rate through six equal tanks, it will be at six times that rate through each, and consequently there will be such rapid settlement of the heavier solids in the first tank, that it will be full before septic action arises there to any important extent. If this first tank therefore is in duplicate, it might frequently

be emptied altogether, and if it is also used as a grit tank, the sludge will be dense, with a relatively small proportion of water.

Removal of Scum.

Another point worth attention is the question of removing the scum of a septic tank. Several experiments were made, and it was found quite easy to remove scum which at the time was 6 to 9 inches thick at one side of the tank for a width of about two yards. If this is done on the side to which blows the prevailing wind, the remaining scum will soon be driven into the cleared space, and so gradually the whole be removed. No nuisance was found to arise in doing this at Leeds ; the matter was left in heaps, which soon drained dry, and was then like a bank of soil. Matter removed from septic tanks in this wav—and it can only be done at all when the scum is dense enough—is not sludge, but is in a form to be at once handled and carted away. The formation of scums on septic tanks is, however, very erratic. At some periods they are very thick, so as almost to bear the weight of a person, and at other times disappear altogether, these variations being due to climatic conditions, mainly such as wind, cold and rain. The volume of matter obtained by the removal of the scum is not important.

Utility of the Removal of Scum.

The scum on a septic tank does not seem at all a necessity or an aid to septic action. When at Leeds the scums had been removed by hand or had of themselves dwindled and disappeared, no difference was found in the analysis of the effluents, except that the flushes of suspended matter in the effluent—which are very inconvenient—seemed to coincide with movements of the scum, especially heavy rain falling upon it and causing it to sink below the surface. Probably, if the surface could be kept free from scum, these inconvenient flushes might disappear.

If by any means the suspended matter in the effluent from septic tanks could be kept down, say to 3 or 4 grains per gallon, it would do away with one of the main objections to this form of settlement.

Best Rate of Flow.

A point of great importance is the question as to which rate of flow through these tanks gives the best results. With the intention of obtaining data bearing upon this subject, experiments previously detailed were instituted with tanks, similar in every respect, through which sewage was passed at rates which would fill the tanks in 12, 24, 48 and 72 hours. They showed that any increase of flow above what is sufficient to fill the tank in 24 hours is attended with a corresponding decrease in the quality of the effluent, whilst a reduction of speed to the 48 and 72 hours rate gives very little advantage. If the flow is increased too much, the tank will become filled with sludge before septic action is produced.

AVERAGE OF ANALYSES REFERRING TO THE EFFECT OF DIFFERENT RATES OF FLOW THROUGH OPEN SEPTIC TANKS.

GRAINS PER GALLON.	12 hours' Flow.		24 hours' Flow.		48 hours' Flow.		* 72 hours' Flow.	
	Analysis.	Purification.	Analysis.	Purification.	Analysis.	Purification.	Analysis.	Purification.
Total Solids ...	87·7	—	78·2	—	78·6	—	73·9	—
Suspended Solids	19·2	52 %	11·4	71 %	10·9	73 %	9·9	76 %
Free NH_3. ...	1·56	22 %	1·51	24 %	1·62	19 %	1·79	37 %
Alb. NH_3. ...	·540	50 %	·452	58 %	·387	64 %	·343	52 %
Oxygen absorbed (4 hrs., 80° F.)	5·21	45 %	4·84	49 %	4·30	55 %	3·59	55 %

* Experiment at later date with weaker sewage.

Advantages of Septic Tanks.

Briefly, the advantages of septic settlement are:

1. That the area of tanks being necessarily large, there is an equalisation of the sewage, producing an effluent of fairly constant composition. This is important at Leeds, where the sewage and trade effluents vary very much from hour to hour.

   The large tank area is, of course, costly.

2. That septic action digests a portion of the suspended matter, such digestion amounting at Leeds to about 30 per cent. of the quantity in the sewage, and, therefore, to that extent reduces sludge production.

It has been claimed that the chemical changes in the septic tank are of great service in facilitating nitrification in the following processes, whether on contact beds or percolating beds; and in some cases it has been maintained that the septic antecedents are a necessity to successful filtration.

The experience at Leeds does not support either theory, but this point will be found fully dealt with later, in connection with percolating filtration.

Experiments in the Filtration of Septic Tank Effluent.

The filtration of crude sewage on contact beds not having proved practicable (see p. 37), and the experiments in septic settlement having shown that the amount of suspended matter per gallon could be reduced by that process from 42 to 13 grains, the filtration experiments with contact beds were now resumed, but this time with septic tank effluent.

The old No. 1 and 2 contact beds which had been used for the crude sewage experiments already detailed, were again used in this case, but as the primary bed had been choked, its material was first taken out and it was replaced with smaller clinker. The suspended matter in the septic tank effluent is in a finely divided condition, and it was desired as far as possible to prevent it getting down into the body of the bed, and rather to keep it on the surface, therefore, in the primary bed fairly small clinker from $\frac{3}{8}$ to $\frac{5}{8}$ inches was used for the body of the bed, and on the top were placed about four inches thick of fine material consistng of small screenings of coke and clinker of about $\frac{1}{8}$ inch.

The distribution was simply by channels hollowed out of the surface and lined with the fine material.

The secondary bed which had been used since October, 1897, in the crude sewage experiments, did not have its material replaced. It was only dug over to a depth of two feet, levelled, and then channelled. It had been rested for three months, during the re-filling of the primary bed.

These filters were started on July 15th, 1901, only two fillings per day being given, and, in addition, they received a week's rest in every four, so that in no sense were they overworked. The whole object of this experiment was to see how far the water capacity could be maintained.

The experiment has continued up to May, 1905, with no change in the conditions other than the natural variations of the suspended matter in the septic tank effluent.

The cycles were of 12 hours; $1\frac{1}{2}$ hours filling, 2 hours standing full, 1 hour to run off, and $7\frac{1}{2}$ hours resting.

During the three weeks' working period sludge accumulated in the grips, which during the week's rest dried so as to be easily removed by scraping or raking on to the space between the grips. By doing this every month, the grips were kept open and the liquid easily distributed over the surface.

Notwithstanding the precautions taken to prevent as far as possible the access of the suspended solids to the interior of the primary filter, and the easy method of working the filter, the water capacity has gradually decreased as shown in the following table:—

IN GALLONS.

Date.	Capacity.	Loss or Increase.	Date.	Capacity.	Loss or Increase.
July 16th, 1901.	86,900	—	June 5th, 1903.	60,000	Nil.
Aug. 2nd, ,,	83,300	– 3,600	July 3rd, ,,	60,000	,,
Aug. 30th, ,,	80,100	– 3,200	July 31st, ,,	60,000	,,
Sept. 27th, ,,	79,100	– 1,000	Sept. 25th, ,,	58,600	– 1,400
Oct. 25th, ,,	77,700	– 1,400	Oct. 23rd, ,,	59,400	+ 800
Nov. 22nd, ,,	76,200	– 1,500	Nov. 20th, ,,	56,200	– 3,200
Dec. 20th, ,,	79,100	+ 2,900	Dec. 18th, ,,	56,200	Nil.
Jan. 17th, 1902.	74,200	– 4,900	Jan. 15th, 1904.	55,700	– 500
Feb. 14th, ,,	73,300	– 900	Feb. 12th, ,,	53,200	– 2,500
Mar. 14th, ,,	71,800	– 1,500	Mar. 11th, ,,	52,700	– 500
Apl. 11th, ,,	70,300	– 1,500	Apl. 8th, ,,	51,800	– 900
May 9th, ,,	70,300	Nil.	May 6th, ,,	52,700	+ 900
June 6th, ,,	68,900	– 1,400	June 3rd, ,,	50,900	– 1,800
July 4th, ,,	70,300	+ 1,400	July 2nd, ,,	49,300	– 1,600
Aug. 1st, ,,	68,400	– 1,900	July 29th, ,,	49,300	Nil.
Aug. 29th, ,,	67,400	– 1,000	Aug. 26th, ,,	48,100	– 1,200
Sept. 26th, ,,	67,400	Nil.	Sept. 23rd, ,,	47,400	– 700
Oct. 24th, ,,	65,900	– 1,500	Oct. 21st, ,,	45,700	– 1,700
Nov. 21st, ,,	64,500	– 1,400	Nov. 18th, ,,	42,500	– 3,200
Dec. 19th, ,,	65,900	+ 1,400	Dec. 16th, ,,	40,300	– 2,200
Jan. 16th, 1903.	64,000	– 1,900	Jan. 13th, 1905.	39.600	– 700
Feb. 13th, ,,	64,000	Nil.	Feb. 10th, ,,	36,600	– 3,000
Mar. 13th, ,,	62,000	– 2,000	Mar. 10th, ,,	36,400	– 200
Apl. 9th, ,,	62,000	Nil.	Apl. 7th, ,,	37,600	+ 1,200
May 8th, ,,	60,000	– 2,000			

During the whole of this period of nearly four years, the filtrates were remarkably good. The liquid was practically free from suspended matter, and, although the freshly-drawn effluent was slightly opalescent, it soon cleared on standing in the inspection chamber, and objects in a 3 ft. depth could be easily seen.

The Free NH_3, Alb. NH_3 and Oxygen absorbed, values were invariably very low, whilst the Nitrate value was high for Leeds. The effluent was shewn to be non-putrefactive by the incubator test. Samples saturated with air absorbed on the average only 16·5 % of the dissolved oxygen in 24 hours, many samples absorbing none.

The effluent was well aerated, green algæ grew very profusely in the basin, and gold-fish lived in the basin for long periods.

The following is the average of all analyses made of the effluents from 1901 to 1904 :—

Grains per Gallon.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitric N.	Incubator Test.		Solids.	
					Before.	After.	Soluble.	Suspended
Crude Sewage	2·19	·607	7·87	—	—	—	74·7	44·0
Effluent from Septic Tank	1·29	·424	5·46	—	—	—	63·9	18·0
Filtrate from No. 1 Bed...	·799	·182	1·17	—	—	—	64·1	6·5
,, ,, No. 2 ,, ...	·237	·046	·358	1·23	·127	·149	69·5	·24
Percentage Purification ...	89%	92%	95%	—	—	—	6%	99%

The results as to purification were, therefore excellent, but the experiment demonstrated conclusively that, even with septic tank effluent, the capacity of the contact beds became steadily reduced, so that at comparatively short intervals it would be necessary to either wash or renew the material.

Whether this will prove less costly than thorough chemical precipitation will depend on local circumstances, and mainly on the possibility of dealing with large quantities of sludge or sludge cake.

Single Contact Filtration of Closed Septic Tank Effluent.

It will be convenient here to deal with the filtration of the effluent from the closed septic tanks on the Exeter system, referred to at pages 54 to 56.

The designers provided only single contact, that is, filtration through a single bed.

The effluent passed over six single contact beds. Four of them were filled with fine coke, and two with fine clinker about half inch in thickness. Of the six beds, only five were in use each day, so that the beds were allowed to rest in rotation for one day in six. Eight beds were filled every 24 hours, three of the beds receiving two fillings, and two only one filling, during that period; so that, taking the day's rest into account, the beds average $1\frac{1}{3}$ fillings per 24 hours. The process of filling and discharging was by means of an ingenious automatic gear, actuated by an arrangement of buckets and syphons. The septic tank effluent was distributed over the beds by three channels running across the filter, and collected by drains laid on the bottom.

These beds were permanently started on September 22nd, 1899, but were only allowed to work during the day. From October 5th, 1899, the process has been carried on throughout the 24 hours.

The filtrates obtained at first were dark coloured and very opalescent, and continued so until November, when an improvement took place, although the filtrate, when seen in bulk, remained dark coloured.

At the end of a few months pooling on the surface of the beds began to take place, and soon after 12 months it was necessary to dig over the beds to the depth of one foot.

As time went on the finer beds, Nos. 4, 5 and 6, had to be dug over to a depth of three feet. In these cases it was found impossible to replace all the material, some 200 cubic feet being left over, this being due doubtless in part to the presence of accumulated matters added to the material of the filters.

After the first time there was not much gain in capacity by the turning over of the material. Now, after five years' working, these beds require the material to be not only turned over, but washed or replaced.

The following Table gives the original capacities and the reductions during the five years :—

CAPACITY OF THE EXETER SINGLE CONTACT BEDS. (GALLONS).

DATE.		No. 1 Bed.	No. 2 Bed.	No. 3 Bed.	No. 4 Bed.	No. 5 Bed.	No. 6 Bed.	TOTAL.
Sept. 22nd to 29th,	1899.	4,770	5,750	5,810	5,240	5,200	4,890	31,660
Oct. 23rd to 26th,	,,	4,680	4,980	5,140	4,770	4,940	4,350	28,860
Nov. 27th to Dec. 2nd,	,,	4,220	4,600	4,670	4,420	4,450	3,900	26,260
Jan. 1st to 6th,	1900.	4,350	4,700	4,700	4,350	4,520	4,030	26,650
Jan. 29th to Feb. 3rd,	,,	4,250	4,580	4,660	4,220	4,450	4,000	26,160
Mar. 5th to 10th,	,,	4,270	4,490	4,610	4,340	4,350	3,980	26,040
Apl. 9th to 16th,	,,	4,230	4,380	4,460	4,630†	4,770†	4,310†	26,780
May 7th to 12th,	,,	4,190	4,298	4,370	4,530	4,450	4,170	26,000
June 11th to 16th,	,,	4,050	4,090	4,300	4,370	4,330	4,140	25,280
July 16th to 21st,	,,	4,100	4,040	4,200	3.950	4,210	4,190	24,690
Aug. 21st to 25th,	,,	3,870	3,800	4,180	3,950	3,900	3,800	23,500
Sept. 25th to 29th,	,,	3,800	3,600	3,900	3,830	3,730	3,800	22,660
Oct. 29th to Nov. 2nd,	,,	3,500	3,320	3,700	3,620	3,250	3,550	20,940
Dec. 3rd to 8th,	,,	3,250	3,100	3,390	3,300	3,000	3,270	19,310
Jan. 6th to 11th,	1901.	3,650†	3,730†	3,950†	3,750†	3,400†	3,650†	22,130
Feb. 12th to 16th,	,,	3,530	3,500	3,800	3,570	3,050	3,150	20,600
Mar. 18th to 21st,	,,	3,250	3,400	3,700	3,520	2,850	2,900	19,620
Apl. 23rd to 27th,	,,	3,230	3,360	3,650	3,480	2,720	2,850	19,290
July 15th,	,,	2,920	2,780	3,300	3,470	2,670	2,740	17,880
Aug. 19th,	,,	3,050†	3,060†	3,540†	3,680†	2,820†	2,980†	19,130
Sept. 30th,	,,	2,900	3,030	3,310	3,600	2,600	2,790	18,230
Nov. 5th,	,,	2,650	2,900	3,100	3,440	2,570	2,550	17,210
Dec. 16th,	,,	2,770	2,990	3,210	3,620	2,650	2,590	17,830
Jan. 20th,	1902.	2,630	2,850	3,000	3,400	2,450	4,170*	18,500
Feb. 24th,	,,	2,600	2,630	2,820	3,150	2,300	3,900	17,400
Apl. 7th,	,,	2,500	2,610	2,800	3,120	2,250	3,620	16,900
May 12th,	,,	2,430	2,550	2,680	3,360	2,190	3,590	16,800
June 16th,	,,	2,460	2,450	2,650	3,540	2,190	3,590	16,880

* Denotes Bed turned over to a depth of 3 feet or more.

† Denotes Feed Channels cleaned out and Bed top trimmed.

CAPACITY OF THE EXETER SINGLE CONTACT BEDS (CONTD.) GALLONS.)

DATE.		No. 1 Bed.	No. 2 Bed.	No. 3 Bed.	No. 4 Bed.	No. 5 Bed.	No. 6 Bed.	TOTAL.
July 21st,	1902.	2,500	2,570	2,630	3,510	2,070	3,500	16,780
Aug. 25th,	,,	2,380	2,480	2,600	3,290	2,000	3,260	16,010
Sept. 29th,	,,	2,750†	2,560†	2,670†	3,330†	4,720*	3,600†	19,360
No date ...	...	2,750	2,250	2,680	3,150	4,450	3,600	18,880
Dec. 2nd to 8th,	,,	2,540	2,080	2,645	2,420	4,190	3,080	16,950
Jan. 5th to 12th,	1903.	2,390	2,020	2,760	4,590*	3,610	2,760	18,130
Feb. 2nd to 7th,	,,	2,290	2,010	2,740	4,450	3,500	2,490	17,480
Mar. 2nd to 7th,	,,	2,450	2,130	2,750	4,370	3,370	Not Tested.	15,170
Apl. 1st to 7th,	,,	2,380	2,090	2,780	4,220	3,310	2,350	17,130
May 1st to 9th,	,,	2,340	2,030	2,740	3,990	3,060	2,080	16,240
June 1st to 7th,	,,	2,290	1,970	2,660	3,830	2,940	2,000	15,690
July 1st to 7th,	,,	2,450†	2,200†	2,900†	3,650†	2,860†	2,090†	16,150
Aug. 3rd to 8th,	,,	2,360	2,060	2,750	3,500	2,680	1,890	15,240
Sept. 1st to 7th,	,,	2,310	1,990	2,660	3,320	2,500	1,730	14,510
Oct. 1st to 7th,	,,	2,300	1,950	2,600	3,200	2,310	1,560	13,920
Nov. 2nd to 7th,	,,	2,360	2,040	2,630	3,150	2,200	1,440	13,820
Dec. 1st to 7th,	,,	2,330	2,000	2,560	2,950	2,020	2,200*	14,060
Jan. 1st to 7th,	1904.	2,310	1,970	2,470	2,900	1,860	1,800	13,310
Feb. 8th to 13th,	,,	2,200	1,900	2,280	2,810	1,680	1,610	12,480
Mar. 7th to 12tth,	,,	2,190	1,930	2,260	2,840	3,240*	1,510	13,970
Apl. 4th to 9th,	,,	2,200	1,900	2,240	2,790	3,120	1,470	13,720
May 2nd to 7th,	,,	2,240	1,980	2,340	2,950	2,980	1,470	13,960
June 1st to 7th,	,,	2,280	2,050	2,420	3,000	2,860	1,580	14,190
3 months ending Sept. 5th,	,,	2,210	2,010	2,390	2,880	2,780	1,970	14,240
Dec.	,,	2,050	1,830	2,190	2,600	2,450	1,750	12,870
Loss of Capacity ...	...	2,720	3,920	3,620	2,640	2,750	3,140	18,790
Percentage Loss of Original Capacity	...	57·0%	61·1%	62·3%	50·3%	52·8%	64·2%	Average. 59·3%

* Denotes Bed turned over to a depth of 3 feet or more.

† Denotes Feed Channe cleaned out and Bed top trimmed.

The filtrates, although invariably non-putrescent, were not satisfactory on analysis.

The albuminoid ammonia was usually above the Rivers Board Provisional Standard, while the liquid was opalescent and dark coloured in appearance, and very often had considerable amounts of suspended solids. It was remarkable that there was rarely any oxygen in solution.

No green growths were visible in the outflow basin or channels.

The following is the average of all analyses made during this period :—

GRAINS PER GALLON.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed	Nitrogen as Nitrates.	Suspended Solids.	Soluble Solids.
Crude Sewage	2·15	·742	8·16	—	42·8	74·3
Effluent from Closed Septic Tank	1·59	·356	3·84	—	11·2	61·7
Filtrate	·673	·129	·755	·530	3·43	62·1
Percentage Purification ...	68·7%	82·6%	90·7%	—	92·0%	16·4%

Single Contact insufficient.

In brief then, these filters working with septic tank effluent, containing an average of 11 grains per gallon of suspended solids, lasted five years before reaching the urgent necessity of washing or renewing the material. They gave considerable purification, but not sufficiently good to pass the Rivers Board Standard. Single contact filtration, therefore, even of septic effluent, was found insufficient to give a well oxidised result, but no doubt the addition of secondary beds would have made the resulting effluents excellent.

Single Contact Filtration of Open Septic Tank Effluent. Bed No. 8.

Another experiment in single contact filtration of effluent from the open septic tank was made on a bed known as No. 8, which had an area of 490 square yards, a depth of $3\frac{1}{2}$ feet, and clinker material from $\frac{3}{8}$ inch to 1 inch.

Work was started on March 20th, 1899, with three fillings per 24 hours, and two hours contact. The septic effluent put on the bed contained at first an average of 9 grains per gallon of solids in suspension, which, however, increased to 13 later on.

AVERAGE OF ANALYSES, MARCH, 1899, TO JUNE, 1900.

GRAINS PER GALLON.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	Suspended Solids.	Soluble Solids.
Sewage	2·22	1·048	9·09	—	44·1	75·5
Effluent from Septic Tank	1·83	·445	4·18	—	13·0	64·6
Filtrate from No. 8 Bed..	1·24	·164	1·06	·047	6·7	64·8
Percentage Purification...	44%	84%	88%	—	84%	14%

These results are similar to those detailed on last page in reference to the filtration of the Exeter effluents, and, although they are rather worse, it must be noted that this bed was worked at 3 fillings a day, while the Exeter beds received only 1½ fillings in 24 hours. Bed No. 8 did, in fact, double the work.

The result, however, confirms that of the Exeter experiment, that single contact filtration of Leeds septic effluent does not give results good enough to pass the Rivers Board Standard.

Reduction of Capacity by Consolidation.

The reduction of capacity in this experiment was remarkable. Within six months it had fallen to nearly one-third of the original sewage capacity, viz., from 29,500 gallons to 10,700.

The bed was rested for six weeks, then dug down and turned over, when it was noticed that there was no deposit below the upper two inches. Below that depth the clinker was comparatively clean.

On restarting the capacity was 26,900 gallons, which in eight months fell to 9,800 gallons.

There can be little doubt that in this case, as in the next, the loss of capacity was due much less to accumulation than to consolidation.

Both as regards analytical results and reduction of capacity, it is interesting to compare the last experiment with the following, made with Bed No. 7.

Single Contact Filtration of Lime Precipitation Effluent.

This was an experiment also in single contact filtration, but instead of septic tank liquor, the effluent from lime precipitation was used, by which process the bulk of the Leeds sewage was being treated. The two experiments were in a sense parallel, for, on comparing the analytical table, the septic effluent and the precipitation effluent will be found to be very similar, the only material difference being that the septic effluent contained an average of 13 grains suspended matter, while the other contained 9·4.

Bed No. 7 had an area of about 900 square yards and a depth of 3 feet 6 inches. It was filled with clinker smaller than 1 inch and larger than $\frac{5}{8}$ inch. The bed was not underdrained. No special system of distribution was adopted. The lime effluent was allowed to enter the bed at one corner, and in time, as the surface in that corner began to become choked, the liquid spread further over the bed until, after six months' working, it spread over two-thirds of the surface before finally disappearing.

It was started on March 8th, 1899, and was worked with three fillings per 24 hours, and with two hours' contact, until October 20th, *i.e.*, for rather over seven months.

The filtrates first obtained were strongly opalescent, but as the bed improved in condition the filtrates also improved, though they had a strong yellow colour, and on standing

deposited a copious buff-coloured precipitate which consisted chiefly of iron. The last runnings from the bed were usually very clear. The results, however, never reached the standard obtained by the double contact treatment of crude sewage on Beds Nos. 1 and 2, nor even those attained on Beds Nos. 3 and 4, and 5 and 6. The following table gives the average analyses over the whole period :—

Average of Analyses.

Grains per Gallon.	Free. NH_3.	Alb NH_3.	Oxygen Absorbed	Nitrogen as Nitrates.	Suspended Solids.	Soluble Solids.
Sewage	2·22	1·048	9·09	—	44·1	75·5
Lime Effluent	1·76	·434	4·53	—	9·4	71·7
Filtrate from No. 7 Bed	1·25	·165	1·02	·053	4·5	64·0
Percentage Purification...	43%	84%	88%	—	89%	15%

A comparison of this table with that given for the former experiment (see p. 75) will show that with liquor of a similar composition, the one septic and the other not, treated in both cases on similar filters by single contact, the purification and analytical results were also very similar.

In this case also single filtration did not give analytical results good enough, but the filtrate was evidently well aerated, for green growth appeared in the channels.

It had been anticipated that in filtering the effluent containing only nine grains per gallon of suspended solids, the rate of sludging up would be very small. The result, however, was disappointing, for the reduction of capacity was larger than that of the primary beds dealing with crude sewage. The original sewage capacity on March 24th, 1899, was 55,700 galls. and by October 20th, 1899, it had fallen to 21,600 galls.

Reduction of Capacity by Consolidation.

As it was impossible to account for this unexpected large reduction of capacity, the experiment was stopped at the end of October, 1899. The bed was rested for two months, and during this period it was dug down, turned over, thoroughly loosened, and completely underdrained with 3 inch agricultural drain pipes. The effluent which had been going on to the bed contained 9·8 suspended solids, and the filtrate 4·8, so that 5 grains remained behind in the bed. These 5 grains reckoned on the total volume of sewage dealt with in the seven months was far from accounting for the reduction of capacity, even if none of it had been digested. It was found in fact that there was very little accumulation of matter in the bed, but the material of the bed had sunk and become consolidated, so as to form almost one mass, as a consequence, no doubt, of the alternate filling and emptying of the bed, and the slight rise and settlement of the material at each turn of work; in short, the reduction of capacity appeared to be due very much to consolidation of a fine material of unequal size.

On re-starting on Jan. 3rd, 1900, the capacity was found to be 53.500 gallons, that is within 2,200 of the original capacity. The turning over of the material had raised the level of the bed some 4 inches.

The second stage of the experiment was under the same condition, and gave similar analytical results to those already noted, and also showed a rapid fall of capacity, though not so rapid as in the first period. At the end of 13 months the capacity had fallen from 53,500 to 15,100 gallons.

It was not thought useful to continue the experiment with this material, which was broken clinker from the City Destructors, insufficiently vitrified and friable.

TABLE SHOWING LOSS OF CAPACITY OF NO. 7 BED.

						Loss of Capacity.
Capacity on	January 3rd,	1900	= 53,500	galls.	...	—
,,	Feb. 2nd,	,,	= 50,300	,,	...	3,200 galls.
,,	Mar. 12th,	,,	= 44,400	,,	...	5,900 ,,
,,	Apl. 11th,	,,	= 39,600	,,	...	4,800 ,,
,,	May 10th,	,,	= 35,200	,,	...	4,400 ,,
,,	June 7th,	,,	= 30,000	,,	...	5,200 ,,
,,	July 5th,	,,	= 25,600	,,	...	4,400 ,,
,,	Aug. 2nd,	,,	= 24,100	,,	...	1,500 ,,
,,	Aug. 31st,	,,	= 23,400	,,	...	700 ,,
,,	Sept. 28th,	,,	= 20,800	,,	...	2,600 ,,
,,	Oct. 26th,	,,	= 19,300	,,	...	1,500 ,,
,,	Nov. 23rd	,,	= 17,600	,,	...	1,700 ,,
,,	Dec. 21st,	,,	= 17,600	,,	...	Nil.
,,	Jan. 18th,	1901	= 16,100	,,	...	1,500 ,,
,,	Feb. 15th	,,	= 15,100	,,	...	1,000 ,,

Experiments with Percolating Filters.

So far, this Report has referred to filtration experiments on contact beds only. We now come to the question of filtration on percolating beds, sometimes referred to as trickling filtration or continuous filtration. This latter term is intended to indicate that, whereas in the contact beds the action is intermittent, on the percolating beds the action continues without regular cycles of rest. The term "continuous filtration" is, however, inconvenient, because in distributing sewage on the surface of percolating or trickling beds, it is found in practice useful to have a certain intermittence, amounting indeed only to a few minutes. In this Report, therefore, the term "percolating filtration" will be used.

In 1898 there was very little information on this branch of the subject, and the variety of experiments carried out at Leeds during the two following years in percolating filtration, particulars of which now follow, have given very interesting and valuable information.

Whittaker Bed. Septic Effluent.

The first experiment was with septic effluent, and the bed was constructed under the advice of Mr. Whittaker, whose installation at Accrington had been visited. As in a percolating filter there is no water pressure, the construction may be very simple. In this case a circular bed was formed by wood laths kept together by iron bands. Within this light screen the clinker was piled up. On the bottom there was a circular layer of concrete, having an 18 inch collecting drain pipe running along one diameter. This drain formed the main carrier for the filtrate, and was perforated with small holes, and with larger holes in the sides to take 9 inch pipes having a fall to the larger pipe, and themselves perforated with holes.

A manhole was provided vertically from the centre of the bed, having a diameter of 6 feet and a height of 10 feet 6 inches, formed of open brickwork.

Clinker used was between 3 inches and 1 inch, except around the manhole and the extreme circumference, where there was a layer of very coarse clinker.

Effluent obtained from the No. 1 open septic tank was pumped by means of a pulsometer to the Whittaker rotating sprinkler, and by it distributed in a shower over the whole surface.

The bed was started on March 9th, 1899, at the rate suggested by Mr. Whittaker, of 600 gallons per square yard, *i.e.*, at 3,000,000 gallons per acre per 24 hours. The first filtrates were exceedingly bright and clear, due no doubt to the suspended solids being at first retained by the bed, but the filtrate gradually became turbid.

By March 24th the top layer of the filter was covered with a deposit, and the bed began to show signs of surface choking, pools of water being formed upon it. On April 4th, 1899, the number of pools had increased so that the septic tank effluent began to run down the centre manhole and the sides. The flow was therefore reduced to 250 gallons per square yard, that is nearly to one-third, as evidently the larger volume could not pass through the filter as soon as any deposit or growth took place on the surface. But still the effluent gathered in pools on the surface, though the reduced work given to the filter gave improved results (on April 9th ·102 Alb. NH_3 and ·337 Oxygen absorbed).

The bed was now allowed to rest from April 13th to April 17th, 1899. This rest allowed the surface to drain dry, but did not prevent the liquid pooling upon the surface on re-starting the bed. The filtrate obtained on the 17th was very good, containing ·77 Nitrogen as Nitrates, but from that date

decreased in quality until May 8th, 1899, when it contained ·26 Alb. NH_3 and ·775 Oxygen absorbed, whilst only a trace of nitrates were present.

This falling-off in the results was due to the surface being covered with an abundant gelatinous mycelium-like growth (Pylobolus), which prevented the effective æration of the filter.

On May 8th the surface was removed to a depth of one foot in order to expose a new surface, it having been noticed that the growth did not extend to more than a few inches. On re-starting on May 9th, 1899, the filtrates were very clear and good, and continued so until May 18th, when, owing to the surface again pooling, the results became unsatisfactory, *e.g.*, Alb. NH_3 = ·19; Oxygen absorbed = ·842.

On May 20th, 1899, the bed was stopped and allowed to rest until May 24th. This rest only produced a slight improvement in the filtrate and very little alteration to the surface pooling.

Mr. Whittaker's idea was that heating of the sewage as it goes upon the bed was not only valuable at all times, but absolutely essential in cold weather, and that it was within practicable limits of cost, because he claimed to require a greatly reduced area of filter, with heated sewage. The condensed steam of the pulsometer, mixing with the sewage increased its temperature, and at Mr. Whittaker's desire steam was in addition directly injected. It was found that this increased the temperature of the septic effluent from 59° at which it left the tank, to 72·5. It was considered quite too costly to do this on a large scale, and as the growth on the surface of the bed appeared to be promoted by the heated effluent, the use of injected steam was discontinued,

and it was found that by the pulsometer alone, the heat of the septic effluent put on the bed was raised from 59° to 67°—about 8 degrees.

From June 1st a fortnight's rest was given to the bed, by which nitrates were freely produced, for the first sample on restarting contained 3·5 grains per gallon of nitrogen as nitrates. Within a fortnight pooling began again and the surface was forked over, when at once better effluents were produced, which fell off as soon as the surface again became choked. This showed how important a clear open surface is to aeration, and how little a part is played by the open sides of such a filter. The choking was due to a vegetable growth, which did not penetrate into the bed more than a few inches.

In order to try to prevent the growth from choking the surface, this was first well forked over and then covered with one foot thick of very coarse coke, which it was thought would leave sufficient air passages. This was on July 10th. A great improvement in the quality of the filtrates was produced, as shewn by the great increase of nitrates, *e.g.*, on July 8th the nitrogen present as nitrates was ·49, and on July 13th ·756. The filtrate continued to be clear from July 10th to July 30th, but from the latter date, large quantities of brown suspended matters came out from the bed, causing the values obtained from the Alb. NH_3 and oxygen absorbed tests to rise considerably. The Free NH_3, however, remained very low (about ·2), whilst the N as nitrates remained over ·7 grains per gallon, shewing that the aeration of the bed was not being interfered with. The coming through of these solids in suspension in the filtrate was at first very disappointing, and was looked upon as condemning the system. Further experience, however, has shewn that a large part of these solids are irreducible, and, therefore, if they do not come out, but stay behind in the filter, they must necessarily choke it up. They were soon found to be non-putrescible, and to be readily settled.

It was now found possible to run for three months before even the coarse coke forming the new surface became itself gradually choked with the growth. The surface was again forked over, and this was repeated about every two months. During the winter months there seemed to be less trouble with the growth. In frosty and even in very cold weather there was only a small decrease in the quality of the filtrate, the use of the pulsometer pump adding to the heat of the sewage.

With the advent of Spring, 1900, the appearance of the filtrate greatly deteriorated. The suspended solids were dark coloured, and the supernatant liquid obtained after settling them out was opalescent, and sometimes threw down a buff-coloured precipitate similar to that from the Contact Bed filtrates.

Filter choked, material too small.

Forking over the surface did not now seem to help matters, and it became evident that there was accumulation of solid matters in the body of the filter, preventing efficient aeration and causing unequal distribution through the filtering material. This choking up of the interior of the filter caused some of the liquid to run down the outside of the filter, and also down the manhole. The filter was therefore allowed to rest for ten days. On re-starting the filtrate was again good, and remained so until May 1st, when signs of deterioration became apparent at the same time as leakage on the sides.

The work of this bed was continued for another year with similar vicissitudes, and was then finally stopped in May, 1901. The material was too small, and for Leeds sewage evidently coarser material would be required. There is no doubt also that the clinker which at first was from 3 in. to 1 in. had very considerably broken down, as was found on digging into the bed.

The following are the average analytical results for the whole of this experiment:— Results in Purification.

Grains per Gallon.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed	Nitrogen as Nitrates.	Soluble Solids.	Suspended Solids.
Crude Sewage	2·21	·939	8·67	—	74·7	40·3
Septic Tank Effluent ...	1·89	·437	4·22	—	64·4	13·1
Filtrate from No. 1 Whittaker Bed ...	·735*	·107*	·627*	·541*	63·0	6·4
Percentage Purification	66·7%	88·6%	92·8%	—	15·6%	84·1%

* Analysis made after rough settlement of suspended solids.

Average of a Number of Comparative Analyses made upon the Filtrate from the Bed, No. 1, with and without Suspended Solids.

Grains per Gallon.	Albuminoid Ammonia.	Oxygen Absorbed.
Filtrate containing Solids ...	·233	1·40
,, after Settlement of Solids	·105	·610

The following analysis may be of interest. The sludge produced by the settlement of the filtrate was washed, and as far as possible freed from the larger living organisms, such as worms, larvæ:—

Loss on ignition	= 31·3	per cent.
Ferric Oxide...	= 31·3	,,
Silica and matter insoluble in acid	= 18·9	,,
Other mineral matters	= 18·5	,,
	100·0	,,

Notwithstanding all the difficulties, the filtrates were always well aerated. Gold fish in the outflow basin lived for over a

year, although the water was turbid with much suspended matter, and living organisms washed out of the filter. The fish became very fat and died, alas! of rich man's gout.

No. 2 Percolating Bed. Septic Effluent.

A second percolating bed was at once put into construction so as to renew the experiment under better conditions, and this time coke was used which was considered less liable to degradation than the soft destructor clinker used for No. 1 bed.

The construction of this No. 2 bed was as follows: Rows of semi-circular perforated tiles, having a diameter of 18 inches, were placed edge-to-edge, and raised above a slightly inclined plane of concrete by means of small brick columns, so that there is a clear air space between the tiles and the concrete floor. Upon the floor thus constructed was built an octagonal pigeon-holed wall, and the space within this wall filled in with coarse coke; first, to a depth of one foot above the pipes by coke not less than two inches in diameter, and the rest of the bed with coke of not less than 1½ inches diameter. Altogether the depth of coke was 9 feet 6 inches.

The septic tank effluent is distributed over the surface by a rotating sprinkler, and the filtrate is collected by a channel running round the concrete floor.

The rate of filtration was 1,000,000 gallons per acre (*i.e.*, 200 gallons per square yard) per 24 hours, working night and day.

The bed was started on September 2nd, 1899. The first filtrates obtained were exceedingly clear but putrescent, shewing that though solids in suspension were being kept back, bacterial action was not yet developed. This continued until September 19th, when the filtrate became turbid from the large quantity of suspended solids coming out through the coarse coke; but, nevertheless, nitrates were present, and the filtrates were non-putrescent in character.

Since then the filtrates have remained turbid but non-putrescent, and no change has been made to the bed itself until April 7th, 1900, when the coke upon the surface, which had disintegrated somewhat, was renewed, because pooling began to appear.

Work was continued night and day, until about six weeks later, when the quality of the filtrate obtained deteriorated. This was considered to be due to the accumulation of solid matter in the filter interfering with effective aeration, and also to some extent causing the liquid to be unequally distributed throughout the bed. The surface of the bed was also choked to a small extent by the usual growth.

On May 23rd, 1900, an interesting experiment was made to see if the matter on the surface, and the accumulations within the bed could be washed out. It had often been noticed that if, for any purpose, the arms of the sprinkler were held from rotating, then within a few minutes the filtrate became very turbid, with an excess of solid matter coming out. This was due to sending the whole volume, which, during the rotation of the arms is distributed over the whole surface, through only a small part of it, and so increasing tenfold the flow through that part. Experiment in Washing Out.

This suggested that with a coarse bed like this No. 2, the bed could be washed out; accordingly a three inch hose, with town's water, was turned on one square yard of the bed, and successively over the whole surface. The bulk of the accumulated solids came out in the first three minutes, during which the filtrate was exceedingly turbid; a test tube with ten inches in it settling down three inches of sludge. After the first few minutes the solids coming through rapidly diminished. With these washed-out solids came out an immense number of cyclops, larvæ, &c. The sludge was found slightly putrescent and it would necessarily contain organic matter in process of

transition. No doubt, if the experiment had been made after a rest of a week or more, the sludge would have been as little putrescent as that which comes out in the normal flow.

On restarting in June, 1900, the bed behaved like a new one, the greater part of the bacterial life having evidently been washed out with the accumulations, but within a month the filtrates were very good, the nitrification rising to 1·3 grains per gallon of nitrates. Work was continued at the normal rate of 200 gallons per square yard (one million gallons per acre) night and day for a second period of 12 months, when, on account of flushes of suspended matter appearing in the filtrate, the bed was again washed, a large quantity of suspended matter coming out, which was only slightly putrefactive, and contained cyclops and larvæ in abundance.

As on the former occasions, it took a month after restarting before the bed got into best condition, but by July 26th, 1900, the filtrates were again very good. Similar results followed another washing out in May, 1901.

In October, 1900, the pulsometer pump, of which the steam condensed in the sewage was replaced by a ram pump, and during the following winter it was found that the withdrawal of the steam from the septic tank effluent, which had previous to the change increased the temperature of the liquid, was not detrimental even during winter. The filtrates were non-putrescent, and even the sludge settled out was only very slightly putrescent.

During the latter part of the winter 1900-1901, trouble was caused by a thick growth forming upon the surface, which necessitated frequent forkings to keep an equal distribution.

During the whole of 1901 the filtrate remained very good, the filter needing very little attention except an occasional forking on the surface where it was necessary to tread when cleaning the holes in the distributor arms. From June 20th to

July 8th, 1901, there were flushes of solids from the filter, but the filter was not washed out on that account, for this was found to be a recurring condition. Again in February-March, 1902, suspended matter came out in excessive amount in the filtrate, but in a few days they became normal. This flushing out of solids was noticed to occur regularly during the early part of each year, and probably has its origin in the activity of animal life in the filter which occurs about this time, worms and larvæ disturbing and loosing the accumulations.

A surface growth also regularly made its appearance about this time, which, if not removed by frequent forkings, impaired the distribution on the filter and produced bad filtrates, by stopping aeration.

In April, 1902, heavy flushes of solids again occurred. These continued until the amount of suspended matter reached a maximum about May 10th, when an improvement set in, and by May 24th they were again normal. From this date onwards the filter worked in a normal manner, needing very little attention until November and December, 1902. Surface growth then again appeared, and repeated forkings were necessary to keep an efficient aeration.

A period of frost in January, 1903, had little effect upon the filtrates. These frosts seemed to have a retarding action upon the growth of the fungus upon the surface of the filter, for during and after them the surface rapidly became clear.

The filter continued to work throughout the year of 1903 in a satisfactory way except for the usual flushes of solids from the filter during May.

At the end of 1903, this experiment, which had lasted over four years, from September, 1899, was stopped, in order that this filter might be used for a comparative trial with settled sewage. The experiment had shown that Leeds septic effluent could be treated day and night for four years on a coarse percolating bed

at the rate of one million gallons per acre, and give excellent filtrates, if their suspended matter were afterwards settled. Two difficulties were met with. (1) That each year during the winter season there was a troublesome development of a fungoid surface growth, tending to close up the surface of the filters and which could only be counteracted by forking over the surface, which would be a serious matter for a large area of beds. The circumstances connected with these growths requires further investigation.

Fungoid Surface Growths.

Suspended Matter in the Filtrates.

(2) The second difficulty was that a few weeks after starting the bed, when it had reached its full maturity of action, suspended solids began to come out with the filtrate, making it look turbid and unsatisfactory.

At first this condition seemed fatal to the system, but it is now looked upon as its chief advantage.

These matters are to the extent of one half, at least, not reducible by bacterial action, and if they do not come through, but stay behind in the filter, that filter must before very long become choked.

The use of a coarse filter permits these matters to come through freely, and such of them as remain behind are disturbed at spring times by the activity of various organisms, and then come out in flushes.

It was to avoid these flushes that the bed was several times washed out. This, however, does not seem to be really necessary. If it be recognised that there must be a further process after the percolation bed, either a process of settlement, or of straining or filtering through fine material, the periodical flushes may be disregarded.

Subsequent Process necessary.

At Leeds the subsequent processes of settlement and of filtration through a few inches of fine material were both tried, and the latter gave the better result, though the former was

the simpler and less expensive. This part of the subject will be dealt with more fully in connection with the "Leeds bed" experiment, further on in this Report.

In concluding the notice of the four years' work of the No. 2 percolating filter dealing with open septic tank effluent, the following table is added to show the analytical averages of the whole period.

Results in Purification.

Grains per Gallon.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed	Nitrogen as Nitrates.	Soluble Solids.	Suspended Solids.
Crude Sewage	2·24	·764	8·24	—	74·8	41·9
Septic Tank Effluent ...	1·66	·379	4·25	—	63·0	12·5
Filtrate from No. 2 Percolating Bed, unsettled	·434	·125	1·12	·759	63·2	8·0
Filtrate from No. 2 Percolating Bed, settled or fine filtered	·435	·071	·493	·745	59·0	2·1
Percentage Purification...	80·6%	83·4%	94·0%	—	21·1%	95·0%

In connection with the general observations on the septic tank experiments (at p. 67), reference is made to the view that the septic or hydrolytic process is a necessity to subsequent successful filtration either by contact or percolating beds.

The experiment with contact bed No. 7 (see p. 76), did not seem to bear out that view, for the effluent from chemical precipitation gave much the same results in single contact filtration as did the septic effluent. It was now desired to try a parallel experiment with percolating filtration.

The percolating bed No. 2, a coarse, coke bed, had been working for four years continously with septic effluent at the rate of 200 gallons per square yard or one million gallons per acre;

and the suspended matter, which of course varied considerably in amount at different times on account of the flushes in the septic tanks, averaged 12 grains per gallon according to the preceding table of analyses.

Percolating Filtration of Settled Sewage.

In order to make a parallel experiment, it was necessary to obtain by natural flowing settlement, without chemicals, an effluent containing about the same amount of suspended matter, and pass this upon the same filter as the septic effluent, and at the same rate of flow.

Bed No. 2 was therefore washed out by turning a hose and town's water on to its surface, and as was pointed out before, the coarse material permitted the accumulations in the filter, and even the bacterial slime to be washed out. The bed was then rested and allowed to dry. No alteration of any kind was made. The sprinkler distribution was the same.

On January 25th, 1904, the flow was turned on. At first the sewage flowed through a settling tank at the 12 hour rate. This carried to the filter too small an amount of suspended matter, and the rate was then increased to an eight hours flow for several months. As this still left too little suspended matter in the effluent, the flow was increased to a four hours' flow, and so continued for the remaining six of the twelve months during which the experiment lasted.

Results in Purification.

The filtrate from the filter throughout this period remained very similar in character to that produced with septic tank effluent and the filter itself behaved in a similar manner. The filtrate was bright and clear when free from suspended matter, and, like the other, was non-putrescent, even with the suspended solids. These were removed by means of the fine filters described in the last experiment.

The following are the average analytical results from January, 1904, to January, 1905 :—

Grains per Gallon.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed	Nitrogen as Nitrates.	Soluble Solids.	Suspended Solids.
Screened Sewage ...	1·63	·582	7·94	—	73·9	40·7
Settled Sewage ...	1·48	·338	3·90	—	68·7	8·5
Filtrate, unsettled ...	·262	·115	1·11	·894	62·8	8·5
,, fine, filtered ...	·228	·060	·631	·984	64·7	4·2
Percentage Purification...	86·0%	89·7%	92·0%	—	12·4%	89·6%

On comparing this Table of Analyses with the foregoing at page 91, it will be seen that, while the average of suspended matter to be dealt with was less in the second than in the first experiment, the analyses of the settled sewage and septic effluent were very similar :

Comparison of Filtration of Septic and Non-Septic Effluents.

Grains per Gallon.		Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	Suspended Solids.
Septic Effluent		1·66	·379	4·25	—	12·5
Settled Effluent		1·48	·338	3·90	—	8·5
Percentage Purification Fine Filtered	Septic ...	80·6 %	83·4 %	94·	—	95 %
	Settled ...	86 %	89·7 %	92 %	—	89·6 %

and the percentage Purification were also very similar.

Without claiming that this experiment was absolutely conclusive, the conditions not being quite identical, it nevertheless goes to shew that previous septic treatment is not a necessity ; and that, from a like amount of suspended solids and organic dissolved impurities, the filtration would give like results.

Crude Sewage Experiments on Percolating Beds.

The experiments with percolating filters had been so far limited to the filtration of sewage, septicised, or simply settled, but from which in either case the bulk of the suspended matter had been removed. The difficulties which had been met with in the endeavour to deal with crude sewage on contact beds, had not encouraged experiments of the same kind with percolating beds.

Ducat Bed.

In 1898-99, however, much was said about Colonel Ducat's fine percolating filter, which was said to be dealing with crude sewage at Hendon. Colonel Ducat was so sanguine that he could deal with crude sewage at Leeds, because of the construction of his bed and the arrangement by which the temperature is maintained by roofing and heating, that without much expectation of success a Ducat filter was put up at Leeds. The area was $\frac{1}{100}$th of an acre, 48·4 square yards, with a depth of 10 feet of small clinkers from $\frac{3}{8}$ to $\frac{5}{8}$ inch. The sides of the bed were built, not of brick, but of drain pipes, 12 inches long and $5\frac{1}{4}$ inches external diameter. This construction secures the complete exposure of the sides of the filter to the air. Outside this perforated wall was a second wall, distant from it about three feet, and built of solid brickwork for the purpose of keeping in the heat, and it carried a roof covered with thatch. The bottom of the bed had six perforated brick channels connected with the outer air, through which passed cast iron hot water pipes connected with a boiler, to supply artificial heat during cold weather. The crude sewage passed through a small grit chamber and a three-sixteenth inch screen to keep back the grosser solids. The distribution was by an ingenious arrangement of tipping troughs, which gave small flushes of sewage at intervals of about a couple of minutes.

A start was made on March 29th, 1900, working the bed, very easily at first for half the day only. Within a fortnight

signs of pooling appeared on the surface, and the filtrate began to deteriorate rapidly. On this fine bed, the suspended matter was all kept back on the surface, and so prevented aeration.

The fact that the filter was perfectly open at the sides did not seem to help matters, nor yet the heating of the sewage which was raised 10 degrees.

It was thought that the chief cause of the choking was due to wool fibre passing the screen and so forming a mat on the bed. To obviate this the sewage, before going on to the bed, was now sent through a three-sixteenth inch screen, and then through a layer of the bed material one inch in thickness. Before restarting, the choked surface was removed to a depth of two inches and replaced by new material.

On resuming work on June 10th, 1900, the filter gave good filtrates—which, at the end of a month, became excellent, giving a purification of from 94 to 96 per cent.

Immediately after, however, pooling on the surface arose and the filtrates rapidly deteriorated, and within a fortnight more became putrescent.

Of necessity the work was stopped, the bed rested, the surface turned over, and finer screening arrangements made. Work was resumed at the end of July, and the filtrates remained very good for nearly two months, although ponding had begun at the end of one month. At the end of the two months a rapid change for the worse took place, putting a stop to the experiment.

This change was very sudden indeed, and did not occur till the whole surface of the filter was practically under a thin layer of wet mud. On September 27th the filtrate had $5\frac{1}{2}$ c.c. of dissolved oxygen per litre, and a week after the analysis shewed none. While the filtrates were good, they were very good.

Twice more the bed was rested, the surface cleaned, and the experiment repeated in the same conditions and with the same results at the end of two months or even less. So bad were the last filtrates that the outflow basin became filled with grey fungoid growths.

Material too Fine for Crude Sewage.

This unsuccessful experiment shewed (1) the hopelessness of attempting to put Leeds crude sewage through a fine percolating filter, even after a careful screening off of fibre, paper, &c. (2) That excellent filtrates were obtained so long as the surface of the filter could be kept open for the admission of air, and while this lasted the transformation and purification were very remarkable. (3) That the choking of the surface was immediately fatal to all purification, notwithstanding the open sides, which seemed to serve little useful purpose. (4) That the roofing in of the filter and heating of the sewage were possibly of some benefit, but not such as seriously to modify the action, or warrant the expenditure.

After the failure of this trial, the Ducat filter was used for over a year in experiments with septic effluent, which of course contained much less suspended matter than the screened sewage used before.

The results while the filter was in good order were always very good, but at the end of two years it was necessary to rest the bed and fork the surface. This filter continued in work for three years, when, owing to internal clogging, it became necessary to stop the experiment. Some very finely divided suspended matter, of brown colour and well oxidised, came through with the effluent, but much remained behind in the fine material of the filter, which ultimately became choked through and could not be washed out.

Material too fine, even for Septic Effluent.

The conclusion seemed obvious that with a fine grade of material it was not practicable to deal with Leeds septic effluent, except at the cost of very rapid choking of the beds. The same

result indeed had been found with the No. 1 percolating bed (see p. 84), although the material in that case was considerably coarser. In the Leeds conditions percolating filters must be constructed of such coarse material that the indigestible suspended matter (and fully half the matters in our sewage are of this character) can come through and be afterwards settled.

Percolation of Crude Sewage through Coarse Material.

The failure of fine material for percolating beds at Leeds, and the fact that with the very coarse No. 2 percolating bed it had been possible to work successfully for four years with septic effluents, led us to think that if a percolating filter were made sufficiently coarse, it might even deal with crude sewage, digesting what was possible, and passing out what was indigestible, in a transformed and non-putrefactive condition, such oxidised suspended matter to be afterwards settled or strained off on very shallow, fine beds.

Accordingly, the following interesting experiments were carried out.

First an experiment on a small scale. There were at the works three small tanks, one below the other, which had been constructed of brick-work, intended for contact beds, but not been put into use. They were rather over 12 feet square and four feet deep.

For the purpose of this experiment, the first of these was filled with the coarsest coke available, the second with coke to about 1 inch and 1½ inches in size, and the third with small coke about five-eighths inch. The distribution was by tipping troughs, and the sewage used was the crude sewage after passage through three screens, the smallest of which was 37 per inch. The first of these screens, which had one-eighth inch mesh, kept back small pieces of paper, matches, &c., and the second and third screens kept back most of the fibre, but all the finely divided solids in suspension passed on to the beds. The keeping back of matter by

the screens, although it greatly facilitated the work, did not remove any important proportion of the solids in suspension, the matters removed being those which usually do not come into the analysis: as paper, matches, fibre, &c.

There is much fibre in Leeds sewage, which it is very important to keep off the filters, as it felts on the surface and is very slowly dissolved.

There were, therefore, three small percolating beds used in succession. There was no side aeration whatever, and at the bottom the filtrates came out and air came in through a 6 inch pipe only.

The first filtrates from the third or fine bed were very clear, the suspended matter being at first entirely kept back by the coke, but after a few weeks these solids began to work through, and the filtrate became somewhat turbid, though giving fair analytical results when the solids had been settled. Trouble, however, arose in two directions, first by the development of a growth in the upper part of the coarse bed, and secondly by the pooling of the sewage on the surface of the finest bed.

Once more fine material failed, and, therefore, the material of the second and third beds was removed and replaced by coarser coke not less than 1½ inch. At the same time semi-circular perforated drain pipes, nine inches in diameter, were placed in the bottom of each bed, thus reducing the coke depth in each case, but securing more effective aeration.

For the tipping troughs on No. 1 Bed a Candy sprinkler was substituted, which had two arms working intermittently, sewage passing for one minute, followed by three minutes' rest. This intermittence, in sprinkling, was in some respects a disadvantage in connection with such coarse material, for the sewage passed through the beds in rushes. On the other hand the intermittence probably proved useful in improving the aeration of the first bed.

A new start was made on March 26th, 1900, at a rate of flow of 750,000 gallons per acre, that is 150 gallons per square yard per day.

This percolating filtration was over three beds of the coarsest coke: the first three feet six inches, and the second and third about two feet six inches each in depth. No doubt it would have been much better to have had this eight feet six inches of coke all in one column, with a single distributor.

The sewage took only a quarter of an hour to pass through the three beds, and the first results were very unsatisfactory with a total purification of about 50 % only. The filtrates gradually improved until in about three weeks the bed had got into condition, but shortly after this, solids began to work through, and made the filtrates turbid. This was the same result which had been noticed before; that the solids in suspension were at first kept back, but gradually worked their way down through the filter until they began to come out with the effluent. These solids were found, however, on coming out, to be different in character to what they were on going in. They settled more readily, and were only very slightly putrescible.

When these solids had been settled from the final filtrate, good analytical results were obtained, namely: ·099 Alb. NH_3 and ·667 oxygen absorbed per gallon.

This result, in view of the short time taken by the sewage in passing over this very coarse coke, was certainly remarkable.

The experiment was continued for seven months until the end of November, 1900, shewing results of 75 to 80 % purification; but as the cold weather came on the quality of the filtrate fell off, and it became evident that the triple distribution involved losing nearly all the heat in the sewage, and that the three separate layers of coke should really be one over the other in one column, and with only one distribution.

The conservation of the heat of the sewage in the use of percolating beds is very important—if the effectiveness of filters is to be maintained in cold weather.

Accordingly, the walls of the third bed were raised to a height of 10 feet from its bottom, and the material from the second and first beds placed in it. Thus the experiment was now renewed with a single bed containing 9 feet of coke, none of it below $1\frac{1}{2}$ and the upper part consisting of 3 inch and 4 inch pieces. The same Candy sprinkler was used for the one distribution.

A new start was made on December 7th, 1900, at the rate of 200 gallons per square yard (one million gallons per acre), with the same sewage as before, fine screened, and was continued for a year and a half. The filtrates contained a large quantity of suspended matter (over 30 grains per gallon were going on to the filter), but the filtrates with this suspended matter in were generally non-putrescent, and after the suspended matter had settled were always so and otherwise of good quality. After the end of November, 1901, however, they showed signs of deterioration, and the aeration values were low. There had been trouble all along by the prolific growth of Pylobolus (a vegetable growth allied to sewage fungus) on the surface coke, which tended to close the spaces between the pieces of coke on the top layer, and so to decrease aeration. Occasional forking remedied this, but after a year's working it was evident that there was some choking lower down. An attempt to wash out the bed was unsuccessful.

Disintegration

In June, 1902, the work was stopped and the material removed from the bed for examination.

It was found that the choking was due to the disintegration of the gas coke, the furnace coke which had been used at the top not being affected, and practically as good as when placed in the filter. The choking began 12 inches below the surface and extended downwards. The second foot was filled with black

septic mud, but below this the mud was brown and well oxidized. The latter contained a very large quantity of worms. The interstices of the coke were entirely filled with broken down coke and sewage debris and in places in the interior local ponding had occurred, as was shown by clearly defined spaces of black mud.

Average of Analyses from December, 1900, to June, 1902.

Results in Purification.

Grains per Gallon.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	Soluble Solids.	Suspended Solids.
Sewage	2·21	·643	6·98	—	71·2	30·9
Filtrate	·614	·202	1·69	·302	66·7	12·9
Percentage Purification ...	72·2%	68·5%	75·5%	—	6·3%	58·2%
Filtrate Settled	·479	·076	·591	·284	—	—
Percentage Purification on Crude Sewage	78·3%	88·1%	91·5%	—	—	—

The changes evidenced in this table were all the more remarkable when it is remembered that the sewage only took three minutes to pass through the filter. The suspended matter worked through very much more slowly, probably requiring a week or more.

The filtrate, with all the suspended matter present, was non-putrescent when the aeration of the filter was effective, and the settled filtrate was uniformly non-putrescent.

Usually, when the solids were removed by sedimentation, the supernatant liquid was clear and colourless, and only in the last stages, when the aeration failed, was it cloudy and yellow.

This novel experiment with crude sewage on a very coarse percolating bed, although it cannot be said to have succeeded, gave such promising results while it was effective, that we felt it should be tried on a larger scale.

Leeds Bed.

Crude Screened Sewage over Coarse Percolating Filter.

There was available the old No. 1 percolating bed already referred to, a circular bed of 45 feet diameter built of wood laths —held together with iron bands (see page 80).

The choked fine material of this bed was accordingly taken out and replaced by the coarsest material, which perhaps has yet been used for any bacterial treatment.

This consisted of the slabs of clinker from the Leeds destructors just as they were raked out of the furnaces—in pieces about 2 inches thick and 12 inches across. The old No. 1 bed was refilled with these placed edgeways, and, to distinguish it, was now called the "Leeds Bed." The depth of this material was $11\frac{1}{2}$ feet, and it was thought well to place on the top 6 inches of gas coke, although, as will be seen, the use of this smaller material was a mistake.

The filter was started on December 23rd, 1901, at the rate of one million gallons per acre (200 gallons per square yard), using sewage, fine screened only, and containing nearly all its suspended matter.

Almost from the first, trouble arose from the thick Pylobolus growth forming on the surface, closing the interstices of the gas coke, and so producing ponding and bad distribution. To obviate this the six inch topping of coke was removed on March 1st, 1902, to expose the much coarser surface of the clinker slab. The filtrates at once improved, and by the middle of April, 1902, satisfactory results began to appear. Nitrates were present in some quantity and the suspendid solids coming out in the filtrates were brown and well oxidized, while after settlement the supernatant liquid was clear and colourless. Work went on day and night without incident until the winter, when pooling began to take place on the surface and the quality of the filtrate deteriorated accordingly.

An examination showed that the surface clinker, originally very coarse indeed, had become broken down, partly by weathering action, and partly by being frequently walked upon to attend to the sprinkler arms, the holes in which required daily clearing out. The destructor clinker is insufficiently vitrified and is very liable to degradation, which is fatal to a filter which depends on the coarse, open material for its continued life. Surface Degradation.

On February 20th, 1903, two feet of this broken down surface material was removed, and replaced by a similar depth of old bricks broken in halves, which it was thought would resist the weathering action better than the clinker. With this alteration, work was resumed on March 31st, 1903, the temperature of the sewage being maintained at 60°F. by the injection of steam. Surface of Half Bricks.

Very good results were obtained; the suspended matter coming out was brown, well oxidised and non-putrescent. The filtrate always contained abundant dissolved oxygen, and the conditions continued satisfactory until the return of cold weather in December, 1903, when surface choking again interfered with aeration, although the brick topping had not broken down.

Average of Analyses from December 23rd, 1901, to December 21st, 1903.

Results in Purification.

Grains per Gallon.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed	Nitrogen as Nitrates.	Soluble Solids.	Suspended Solids.
Sewage	1·95	·554	7·19	—	72·8	37·3
Crude Filtrate	·613	·236	2·167	·245	66·4	14·7
Filtrate, settled	·520	·136	1·030	·308	61·3	4·3
Filtrate, fine filtered ...	·439	·089	·654	·414	62·5	2·5
Percentage Purification of Crude Filtrate ...	68·5%	57·4%	69·9%	—	8·7%	60·5%
Percentage Purification of Filtrate (settled) ...	73·3%	75·4%	85·6%	—	15·7%	88·4%
Percentage Purification of Filtrate (fine filtered)...	77·5%	83·9%	90·9%	—	14·1%	93·3%

Rapidity of Action on Dissolved Impurities.

As in the previous smaller experiment, it was impossible not to be struck by the rapidity in which the chemical changes were brought about. In order to test the speed at which the sewage came through the filter, repeated trials were made as follow :—

About a litre of alkaline fluorescine solution, a very powerful colouring matter, was poured into the channel carrying the sewage to the sprinkler, and the time carefully taken before the colour began to appear in the filtrate as it ran out at the bottom. It usually took three minutes before the full colouration appeared, though there was clear evidence of it after $2\frac{1}{2}$ minutes, the depth of the material in this bed being 12 feet and the grade very coarse indeed. The changes brought about by bacterial action are therefore remarkably rapid as regards dissolved impurities, but it is not, of course, suggested that the action on suspended solids is also so rapid. On the contrary, the dissolution or transformation of the matter in suspension in sewage is a slow one, and when finely divided solids come through a percolating filter, brown in colour and well oxidised, the process has probably required 7 to 14 days. At least, judging from the time which passes before suspended matters come through in a new filter, it takes these fully that time to work gradually down, washed forward by the liquid which itself comes through in three minutes.

Further Process necessary.

Now, as nearly all the suspended solids were being sent on to the filter, a large proportion of them were bound to be present in the filtrates. A sample of the filtrate in a test tube held to the light was seen to be turbid, not by discolouration, but by the presence of finely divided brown particles. These, on resting, settle for the most part rapidly to the bottom of the tube, leaving clear liquid above Obviously to make it practicable to treat crude sewage on percolating beds the filtrate must not be considered as a final result, or the suspended matter would condemn it, amounting as it does to

perhaps 15 grains per gallons in normal conditions, and to much more at time of flushes, which occur periodically. There must be a further process to separate out these matters.

The same necessity arises in dealing with septic effluent on percolating beds—as we have already pointed out.

Experiments in this direction were carried out for the last two or three years at Leeds—(A) by settling, (B) by passing the filtrate through fine material similar to sand.

(A) First as to settling: Four small tanks were used of long rectangular form and 3 ft. deep, holding 15,000 gallons each. Through one of them was passed continuously a flow of the filtrate at the rate of 30,000 gallons per 24 hours, that is at a rate to fill the tank twice in the 24 hours. The best plan was found to be to work each tank thus for one month at a time and then to turn the filtrate into the next tank, allowing the water to drain out of the first, and the sludge, which varied in depth from 12 inch at the inlet to 3 or 4 inches only at the outlet, to drain off its water and then dry, none of it being removed. In this way three months were allowed for the drying of the sludge, which gave rise to no nuisance, having been oxidised in coming through the filter, and being far less putrescible than the sludge settled from sewage before filtration. In drying, the sludge became reduced in bulk to from 3 inch to 1 inch of thickness, and split up into separate small blocks by innumerable cracks. When thoroughly dried it acquired the property of not again increasing in bulk when water was put over it. Accordingly after three months, the tank was again used for settling purposes and new sludge deposited over the dried old sludge. In this way it would be possible to use low-lying lands for the purpose, gradually raising their level with rich soil.

The effluent from these tanks was for the greater part of the year satisfactory, for although not quite up to the provisional chemical standard of the Rivers Board, it contained some

nitrates and dissolved oxygen. During the winter months it was not so good, mainly because the bacterial action in the filters was also less effective, and partly because at that time there seemed to be more minutely divided matter in the filtrate —which did not settle in the tank, and was in winter putrescent. In short the result, though fair, was hardly good enough at this speed of settlement, the purification by the double process amounting to from 75 to 85 %. The following alternative process gave distinctly better results.

(B) In this case the filtrate was passed through a few inches thick of fine riddled clinker dust and ashes not over $\frac{1}{4}$ inch, the process being mainly one of mechanical separation—or filtering, using that term in its strict sense. Incidentally, however, there was no doubt also some bacterial action which was so far useful. As in the former case, four separate areas were provided and one of them used at a time for a month. The material was 6 inches deep, and the area was surrounded by banks two feet high.

The filtrate from the Leeds filter was allowed to flow on to the fine material at will, and as the part near the inlet became coated with deposit the filtrate gradually spread over the whole area, and then rose above it as high as the banks would allow. At this stage the filtrate was turned into the next area, the first was allowed to drain and the sludge on the surface dried and divided up into small pieces by numerous cracks, just like the sludge in the settling tanks.

It had been thought that by harrowing or raking when dry the blocks of dried sludge would be broken up into fine material which might become the material of the filter, but this was not found to be practicable, and therefore the dried sludge had to be raked into heaps and removed, during the several months' interval of rest, and the new, fine surface prepared and raked over.

Although this is not, unfortunately, an automatic arrangement, the results from this fine filtration were very good, except when the filter was allowed to get out of order, and showed purification by the double process of from 83 to 90%, the effluent containing in addition nitrates and dissolved oxygen. (See table of analyses, p. 103).

The best arrangement would certainly be a combination of both plans, that is the filtrate would pass through a settling tank, and then through a fine strainer, which would last a considerable time.

Storm Water Experiments.

We come now to a very valuable series of experiments which were made on the Leeds bed from August to December, 1903.

So few Authorities have been able so far to deal with storm waters at all, so few of the larger municipalities have, indeed, reached the effective treatment of their dry weather flow, that there is very little information available in regard either to the composition or treatment of storm waters, and, therefore, these Leeds experiments should be of considerable interest.

What led us to take them in hand, was the fact that percolating filters worked at such moderate rate of flow, as would give good results, not only brought out oxidised suspended matter, but also left behind accumulations which at first it was thought would have to be washed out to keep the filter from choking. Experience has shown that with a filter coarse enough, washing out will not be necessary, as at certain seasons the accumulations stirred by the activity of certain living creatures such as worms, larvæ, &c., tend to work out with the normal effluent.

It occurred to us, however, that in times of storm an increase of flow on percolating filters would serve a doubly useful purpose, namely to wash out the filters and to purify the storm waters without additional plant.

In order to test how far this might be practicable, during the last seven months of 1903, whenever storms occurred, the dilute sewage was passed to the Leeds bed at three times the normal flow, that is at 600 gallons per square yard instead of 200 (three million gallons per acre instead of one million); and when the dilution was sufficient, at six times the normal rate, that is at 1,200 gallons per square yard instead of 200 (six million gallons instead of one per acre).

At times of rain, the domestic sewage and the trade effluents remain the same, only diluted by the rain water, but especially after a dry time, storm waters bring to the sewers the washings of roofs, gutters, roads, gullies, etc., as well as accumulations left by the slower flow in the sewers themselves. In the beginning of a storm the sewage is often much worse than the ordinary dry weather flow. The excess in impurities, however, consists almost wholly in suspended matters, and if these be withdrawn the liquid left is generally very dilute. In dealing with storm waters, therefore, the difficulty is mainly one connected with suspended matter, which the following table shows sometimes rises at Leeds to nearly three times the normal dry weather average.

Thus on September 25th, the storm sewage contained 103 grains, and on November 25th, 99 grains per gallon of suspended solids, and therefore, the crude filtrate will be expected to bring out with it a large increase of suspended matter, not only of that brought by the storm sewage itself, but of the accumulations in the filter washed out by the increased flow. Thus on August 24th, the filtrate brought out 134·7 grains per gallon, and on September 29th 77·5 grains.

While, therefore, the crude filtrate, including the suspended matter, shows practically no purification except as regards the free ammonia, the same filtrate, after leaving behind its suspended matter in the process of fine filtration shows a purification of 75·3% measured by Alb. Amm. and 90·9% as measured by the oxygen absorbed test, and as shewn in the following Table :—

The following notes will be of service :—

1. Because the increased flow carries through the suspended matter too fast to permit of efficient oxidation, the filtrate during storm times, with all its suspended matter is invariably putrescent; but after removing these solids by mechanical filtration a non-putrescent result is obtained, which has analytical values rather better than the provisional standard and usually even somewhat better than the dry weather results. This is true for both the 600 and 1,200 rates of flow, but naturally better with the former than the latter.

2. At the 1,200 gallons rate of flow the filtrate contained an average of 58 grains suspended matter and the sewage 56 grains per gallon, so that supposing none of the matter was digested, every gallon of filtrate carried away two grains of suspended matter with it, derived from the accumulations within the bed. At the 600 gallons rate of flow the filtrate contained an average of 28 grains and the sewage 44 grains suspended matter per gallon, showing that every gallon of sewage left 16 grains of solids behind to add to the accumulations already there, subject to a partial digestion. If, therefore, the increased flow of storm sewage is to serve the purpose of partially cleansing the filter, a rate of flow of at least 1200 gallons per square yard per 24 hours is necessary.

3. The storm sewage of Leeds frequently contains more suspended matter than the normal sewage, and a larger proportion of mineral to organic matter.

4. During the periods in which storm sewage is sent on to a filter, solids are washed out which are only partially oxidised and which if allowed to remain would produce nitrates by their further oxidation. It follows, therefore, that for some short period after this storm-water treatment, the filtrates are deficient in nitrates and this has a detrimental effect upon their keeping qualities. The beds, however, soon recover during dry weather.

Date, 1903.	Storm Sewage.					Crude Filtrate with its Suspended Solids.								Final Filtrate Fine Filtered.						Rate of Flow.
	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Suspended Solids.	Soluble Solids.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	Incubator Test. c.c. of Oxygen when saturated.	Incubator Test. c.c. of Oxygen after 24 hours.	Suspended Solids.	Soluble Solids.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	Incubator Test. c.c. of Oxygen when saturated.	Incubator Test. c.c. of Oxygen after 24 hours.	Gallons per square yard per day.
August 6th	2·50	·537	6·87	45·1	51·7	·678	·424	4·40	1·20	6·0	0	24·9	53·3	·525	·101	·938	·140	6·0	3·0	1,200
,, 14th	1·67	·462	8·21	55·2	57·2	·778	·280	3·61	0	6·0	0	19·4	60·3	·477	·120	·560	Tr.	6·0	3·0	600
,, 18th	·997	·346	8·21	77·8	35·2	·438	·314	3·76	0	6·0	0	13·0	34·5	·356	·075	·585	Tr.	6·0	2·5	1,200
,, 20th	·756	·242	4·56	32·0	48·0	·362	·309	5·22	H. Tr.	6 0	0	39·9	46·9	·356	·088	·645	H. Tr.	6·0	3·0	1,200
,, 24th	1·38	·294	7·39	50·5	51·9	·488	·457	12·1	0	6·0	0	134·7	49·8	·344	·099	·912	H. Tr.	6·0	H. Tr.	1,200
,, 30th	1·54	·441	5·48	31·5	42·7	·636	·646	5·63	0	—	—	61·6	44·2	·617	·096	·489	V. H. Tr.	—	—	1,200
Sept. 2nd	1·35	·451	5·90	—	—	·840	·591	6·57	0	—	—	—	—	·477	·118	·556	0	—	—	1,200
,, 8th	·862	·378	5·65	—	—	1·16	1·23	15·0	0	—	—	—	—	·420	·090	·720	0	—	—	1,200
,, 10th	1·05	·336	4·89	—	—	·977	·277	4·08	0	—	—	—	—	·656	·107	·960	V. H. Tr.	—	—	1,200
,, 25th	8·40	·252	10·56	103·3	36·4	·288	·309	6·07	0	6·0	0	54·2	41·4	·323	·075	·543	Tr.	6·0	3·0	1,200
,, 29th	946	·189	7·42	73·1	34·7	·429	·398	9·30	0	6·0	0	77·5	44·2	·457	·071	·917	0	6·0	2·0	1,200
October 1st	1·05	·252	4·80	46·2	41·8	·438	·356	6·94	0	6·0	0	70·2	48·4	·339	·094	·494	0	6·0	4·0	1,200
,, 6th	·756	·231	4·03	45·6	45·5	·356	·314	3·36	0	6·0	0	46·3	40·5	·250	·046	·702	0	6·0	4·5	1,200
,, 7th	·378	·063	2·58	—	—	·272	·126	2·11	0	6·0	0	—	—	·339	·036	·408	Tr.	6·0	4·5	600
,, 11th	·504	·084	1·77	18·9	32·5	·164	·107	2·02	·19	6·0	0	20·8	40·5	·193	·037	·272	·19	6·0	4·5	600
,, 14th	·567	·210	4·08	23·2	42·6	·314	·233	2·80	H. Tr.	6·0	0	22·3	50·6	·280	·033	·612	H. Tr.	6·0	4·5	600
,, 19th and 20th ..	·850	·210	3·09	20·9	45·8	·323	·210	2·44	H. Tr.	6·0	0	22·3	49·3	·323	·031	·480	1·54	6·0	5·0	600
,, 22nd	·620	·168	4·97	39·0	48·5	·231	·155	2·28	0	6·0	0	31·3	45·2	·210	·050	·560	0	6·0	3·0	600
,, 24th and 25th ..	·891	·346	4·76	41·8	51·1	·266	·304	2·98	0	6·0	0	28·5	49·5	·306	·031	·406	·084	6·0	3·5	600
,, 27th	·882	·389	3·85	36·2	41·0	·300	·210	2·28	0	6·0	0	25·7	38·5	·292	·048	·826	0	6·0	4·0	600
Nov. 2nd	1·15	·242	3·77	27·3	44·7	·447	·210	1·95	·168	6·0	0	21·1	40·1	·412	·063	·592	·168	6·0	4·0	600
,, 25th	1·36	·546	10·7	99·0	55·1	·420	·350	5·28	0	6·0	0	57·9	49·4	·488	·128	·663	0	6·0	2·5	600
Dec. 3rd and 4th ...	1·17	·357	7·86	54·4	54·1	·382	·276	3·42	0	6·0	0	28·8	51·8	·438	·071	·700	0	6·0	3·0	600
,, 7th and 8th ...	1·21	·368	7·94	73·9	57·1	·420	·296	3·58	0	6·0	0	31·4	50·3	·339	·134	·950	0	6·0	3·5	600
Average	1·05	·308	5·80	49·7	45·8	·475	·353	4·96	·019	6·0	0	41·5	46·4	·384	·076	·645	·030	6·0	3·30	
Percentage Purification on Sewage.	—	—	—	—	—	54·9%	0	1·4%	—	—	—	16·5	0	66·4%	75·3	90·9	—	—	—	

This deficiency of nitrates is, of course, not so marked in the dry weather filtrates following the application of storm sewage at the 600 gallon rate as in those following the 1,200 gallon rate.

5. The 600 gallon rate produces a much better result than the 1,200 rate with respect to the crude filtrate, but this is not so marked in the final filtrates when the percentage purification is taken into account.

600 Gallon Rate (average of analyses.)

	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	Aeration Test. c.cs. O. per litre. Saturated	Aeration Test. c.cs. O. per litre. After 24 hours.	Suspended Solids.	S luble Solids.
Storm Sewage	·937	·287	5·29	—	—	—	44·5	48·1
Crude Filtrate	·359	·229	2·89	·029	6·0	Nil.	28·1	47·7
Purificatio	61·7%	20·2%	45·4%	—	—	—	36·8%	·83%
Filtrate (fine filtered) ...	·341	·065	·585	·049	6·0	3·75	—	—
Purification	63·6%	77·3%	88·9%	—	—	—	—	—

1,200 Gallon Rate (average of analyses.)

	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitrogen as Nitrates.	Aeration Test. c.cs. O. per litre. Saturated	Aeration Test. c.cs. O. per litre. After 24 hours.	Suspended Solids.	Soluble Solids.
Storm Sewage	1·16	·328	6·31	—	—	—	56·1	43·1
Crude Filtrate	·590	·477	7·04	·010	6·0	Nil.	58·0	44·8
Purification	49·1%	Nil.	Nil.	—	—	—	—	—
Filtrate (fine filtered ...	·426	·088	·705	·011	6·0	2·75	—	—
Purification	63·2%	73·1%	88·8%	—	—	—	—	—

6. Where crude screened sewage is sent on to a percolating filter, it is possible in storm times to treat three dilutions of screened storm sewage on the same filter and with an efficient after process to remove suspended matters, to produce results better than the provisional standards.

With six dilutions the results, although not so good, should be acceptable for admission into streams not used for drinking purposes, and at times when they themselves are swollen by rain.

At page 114 later in this report will be found the particulars of experiments upon percolating filters with clarified storm waters, which it was found practicable to treat on the filters at high rates of flow, without further process.

There is no doubt that the frequent rain from July to November, 1903, and the many occasions when the Leeds filter was worked at the high rates of flow, had a bad effect on the dry weather filtrates, robbing them of nitrates and causing the settled filtrate to become somewhat putrescent.

The drier weather at the end of 1903 soon brought about an improvement in the filtrates, though in the cold weather the nitrates did not rise again to the normal. The crude dry weather filtrate had a tendency to putrefy, but both the settled and fine filter effluents were non-putrescent.

Friability of the Clinker used.

It was intended to make some trials in the winter of 1903, to prevent, if possible, the very troublesome growth of pylobolus on the surface of the filter, which possibly might not arise if the surface were covered and light and sun excluded. But the necessity of using this filter for another experiment, which was then urgent, in the percolating filtration of chemically settled effluent, made it necessary to abandon these for the present, and to remove the clinker slabs of the Leeds filter for the new experiment at the much reduced depth of 6 ft.

In removing the clinker, this was found to have become in parts much broken down, and so to have interfered considerably with aeration. The experience with the Leeds destructor clinker was in every case unfortunate, for, being insufficiently vitrified, it is more liable than even gas coke to degradation ; and in the experiments with Nos. 7 and 8 contact beds, and No. 1 percolating bed and the Leeds bed, the degradation of the material was responsible for much of the difficulty experienced.

The choice of suitable material for filters is of the first importance.

Filtration of Precipitated Sewage on Percolating Filters.

An experiment upon the filtration of precipitated sewage was commenced on June 17th, 1904. The filter used was the old "Leeds Filter." The material was replaced with gas-coke of not less than 3 inch size, the depth of bed material, however, being only 6 feet.

Two grains of crude sulphate of alumina and eight grains of lime were used for the precipitation. The rate of flow through the precipitation tank was 12 hours, and the effluent was pumped on to the filter by means of a ram-pump; distribution being brought about by a Candy sprinkler at a rate of 100 gallons per square yard per 24 hours.

As the liquid only contained on the average about 4·4 grains of suspended solids, and as the experiment was commenced in the height of summer, the filter rapidly matured. By July 1st nitrates were present, and on July 7th the Alb. NH_3 was ·102 and the Nitric N. ·689 grains per gallon, the filtrate being quite non-putrescent. On July 25th the following analysis was obtained:—

Free NH_3		·116
Alb. NH_3		·050
Oxygen Absorbed		·598
Nitric N.		1·37
Incubator Test	Before	·202
	After	·171
Suspended Solids		1·4

This experiment extended without change until March, 1905.

During the whole of this period the effluent was very clear and bright, only containing an average of 1·4 grains of suspended matter. It was well aerated, non-putrescent, well nitrated, and its analytical values were very low. Green growths were always present in the effluent channels, in contradistinction to the other trickling bed effluent. Fish lived for eight months in the basin.

During the latter part of 1904 a heavy growth formed over the surface of the filter, but, as the filtrate did not materially deteriorate, no forking was done.

The following is the average of all analyses made from July 1st, 1904, to February 28th, 1905.

Grains per Gallon.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitric N.	Incubator Test.		Solids.	
					Before.	After.	Soluble.	Suspended
Crude Sewage (fine screened	1·76	·649	8·50	—	—	—	75·9	43·7
Precipitation Effluent ...	1·70	·270	2·91	—	—	—	71·8	4·4
Filtrate	·290	·063	·472	1·16	·174	·171	71·1	1·4
Percentage Purification...	83 %	90 %	94 %	—	—	—	6 %	96 %

From July-December, 1904, the effluent, when saturated with air and allowed to stand in well-stoppered bottles at the laboratory temperature, only absorbed an average of 10·3 % of the dissolved oxygen.

Treatment of Clarified Storm Waters.

During periods of storm, the storm water was allowed to flow through a tank at a speed equal to a four hours' flow, about $1\frac{3}{4}$ grains of lime and $\frac{1}{2}$ grain of aluminium sulphate being added to assist the sedimentation of the solids. The clarified storm-water was then distributed over the filter at the rate of 600 gallons per square yard, *i.e.*, six times the normal flow.

The effluents obtained, although containing more suspended solids than normal, were excellent in character, being well aerated, well nitrated and non-putrescent.

Average of all Analyses made during Storms from July, 1904, to February, 1905.

Grains per Gallon.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitric N.	Incubator Test.		Solids.	
					Before.	After.	Soluble.	Suspended
Storm Sewage	1·22	·452	7·62	—	—	—	49·9	61·3
Precipitated Storm Sewage	1·27	·201	1·48	—	—	—	50·0	6·2
Filtrate	·337	·091	·717	·920	·229	·239	62·3	4·9
Percentage Purification ...	72%	79%	90%	—	—	—	—	92%

Commencing March 1st, 1905, the flow of precipitated sewage on to the filter was increased to 200 gallons per square yard in dry weather, and to 1,200 gallons in storm times. This increased rate of flow did not make any appreciable difference to the condition of the effluents. Increased Rates of Filtration.

The following is the average analyses for March, 1905 :—

Grains per Gallon.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitric N.	Incubator Test.		Solids.	
					Before.	After.	Soluble.	Suspended
Storm Sewage	1·61	·693	7·70	—	—	—	71·8	48·6
Precipitated Storm Sewage	1·43	·296	2·10	—	—	—	69·1	3·6
Filtrate	·425	·060	·407	1·07	·147	·168	67·0	·6
Percentage Purification ...	73 °/o	91 °/o	94 °/o	—	—	—	6 °/o	98 °/o

The following is the average of 4 Storm-water Experiments in March, 1905 :—

Grains per Gallon.	Free NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitric N.	Incubator Test.		Solids.	
					Before.	After.	Soluble.	Suspended
Storm Sewage	1·33	·441	8·34	—	—	—	51·6	78·5
Precipitated Storm Sewage	1·46	·252	1·50	—	—	—	66·9	5·0
Filtrate	·437	·092	·601	·790	·254	·292	70·6	5·7
Percentage Purification ...	67 °/o	70 °/o	92 °/o	—	—	—	Nil.	92 °/o

Experiment with Storm Water on a Streaming Filter.

It is interesting to compare the results obtained by the treatment of precipitated storm-water upon a percolating filter, with those obtained from a special storm-filter of the type at present usual. We used an ordinary contact bed with a depth of 3 feet and filled with fine clinker $\frac{3}{8}$ to $\frac{5}{8}$ diameter, to which was added a top layer of very fine clinker to a depth of 6 inches. Distribution was by means of grips cut in the surface material.

During storm times, crude storm water was discharged on to the filter at the rate of 500 gallons per square yard per day until the bed was full. The outlet valves were then opened to such an extent that the rate of discharge was equal to the rate of distribution, thus causing the storm-water to stream through the body of the filter as evenly as possible. This procedure continued until the end of the storm.

In dry weather the filter was allowed to rest.

The following is the average of all analyses referring to this filter:—

JULY, 1904, to FEBRUARY, 1905.

GRAINS PER GALLON.	Free. NH_3.	Alb. NH_3.	Oxygen Absorbed.	Nitric N.	Incubator Test.		Solids.	
					Before.	After.	Soluble.	Suspended
Storm Sewage	1·22	·452	7·62	—	—	—	49·9	61·3
Filtrate	·418	·147	1·70	·343	·272	·317	64·1	9·1
Percentage Purification...	65%	67%	79%	—	—	—	Nil.	85%

GENERAL OBSERVATIONS ON PERCOLATING FILTRATION.

As in contact beds, the effectiveness of percolating filtration depends on effective aeration, and this itself mainly depends on the grade of the material and its permanence—that is, its resistance to degradation.

With very fine material such as sand, capillary attraction would keep the filter waterlogged except at times of prolonged rest. Although such a filter might prove an effective mechanical strainer, there could be no aerobic bacterial action.

With coarser material there would still be capillary attraction round the many points of contact, while the film of liquid passing down the surface of the material and suspended matter settling thereon also take up some of the theoretical air spaces.

The oxidising surface areas of small material are greater than those of larger, and, with thoroughly clarified sewage, it would theoretically be best to use material as small as will guarantee the maintenance of air spaces between the surfaces. From our experience at Leeds, however, we doubt if there will be found advantage in using finer material than one inch even for thoroughly clarified sewage; but for the filtration of septic effluent, or partially settled sewage, it would not be a long time before such a filter became wholly choked, and it would not be practicable to wash it out by increased flow even of clean water. That at least was the Leeds experience. Although, therefore, the speed of passage is quicker through coarse material than through fine, and although the oxidising surface is less, these disadvantages are counterbalanced by greater certainty and permanence of aeration in the use of coarse material even for completely clarified sewage. For sewage containing, say, 10 grains of suspended matter per gallon, and of course still more for sewage which may be used practically crude with 30 to 40 grains per gallon of suspended matter, it is absolutely essential that the material should be very coarse indeed, and, as previous tables will have shown, remarkable results of purification were obtained at Leeds with material of which no part was less than three inch. Necessity for Coarse Material.

A coarse percolating filter then is an organism capable of continued life, because while it digests what it can, it rejects what is beyond its powers or what is indigestible. In Leeds sewage half the suspended matter is indigestible—that is, incapable of being dissolved by bacterial action.

A fine percolating filter receiving suspended matter and passing none out, thus giving a brilliant effluent, must choke up sooner or later, its life being proportional to the amount of the suspended matter in the sewage.

There is another important point to be remembered, and that is, that with certain sewages like that of Leeds, a very inconvenient and at times extensive fungoid growth of the Fungoid Growths.

sewage fungus type takes place on the surface of the material, and with any but very coarse material soon closes the air spaces at the surface.

Side Aeration.

Side aeration seems of little value in percolating filtration. When the surface is choked purification practically ceases, although the sewage drains down into the filter. Filters with solid walls and no side aeration gave good results at Leeds—side aeration tends to reduce temperature in a filter. The conservation of the heat of the sewage is of much importance in winter.

Further Process necessary.

With percolating filtration, unless thoroughly clarified sewage is used, there must be a further process for the purpose of separating or settling out the excess of suspended matter.

At Leeds, slow flowing settlement did not succeed in giving high class results in this direction, because much of the suspended matter is very light and finely divided. On the other hand, filtration through fine material such as fine ashes gave very good results indeed.

Possibility of treating Crude Sewage on Percolating Filters.

Since there must be—with any but thoroughly clarified sewage—a further process beyond percolating filtration, it is an interesting question, whether the process of settlement before the filtration cannot be dispensed with, in favour of settlement after filtration. This is what makes the experiment with the Leeds filter so valuable. That experiment shows that it is practicable to pass sewage, crude except only for fine screening, through a coarse percolating filter, and that the suspended matter settled after filtration is very different from that settled before filtration, being, in fact, at times of normal dry weather flow well oxidised, and generally non-putrescent. The drying of such sludge would be unlikely to give rise to nuisance, as it is in fact humus, or earth. To succeed with the treatment of crude sewage, two difficulties must be overcome—(1) the obtaining of a material which shall not be liable to degradation. (2) the prevention or the reduction of the surface fungoid growth.

The great advantage that would be secured, if it should be found possible to treat crude sewage by (1) screening, (2) percolating filtration (3) settlement of oxidised suspended matter or fine filtering, would be the rapidity of transformation and, therefore, the absence of all danger of nuisance.

The process would be entirely aerobic. No septic decomposition of sewage or of sludge would take place, and, therefore, this rapid aerobic treatment should be of value, where the work is necessarily carried out in the neighbourhood of dwellings.

The action of the oxidising bacteria of a percolating filter on dissolved impurities is strikingly rapid, and the passage of the crude sewage through the screens, the flow through the percolating filter and that through the final fine filter would not occupy more than a quarter hour, and the suspended matter drained off may be safely air dried without evil odour.

The time required would, of course, be longer, if settlement is substituted for the fine filtration, according to the rate of flow of the settlement.

The Leeds experiments in the treatment of septic effluent—and partially settled sewage—were exhaustive, the percolating filter No. 2 having treated septic effluent night and day for four years.

With crude sewage, the coarse percolating filters followed by fine filtration, gave a purification of 85 to 90%, and with septic effluent and partially settled sewage gave a purification of 90 to 94%.

In both cases, the final filtrates carried a fair amount of dissolved oxygen and some nitrates, and would not, therefore, be liable to later putrefactive changes.

As they came out of the percolating filters, the liquids were unsatisfactory to the eye, the fine matter in suspension giving them a dirty, muddy appearance, but after settlement of these, the liquid was clear and of good quality.

The flow of 200 gallons per square yard, or one million gallons per acre, gave time for the oxidation of the suspended matter—which took from 10 days to a fortnight to come through. At this rate accumulation took place in the filter, which it was found quite possible to wash out by increased flow. This increased flow might take place naturally at times of dilution by rain, but then such dilutions bring with them an increased amount, sometimes a greatly increased amount, of suspended matter, not only with crude sewage, but even with septic effluent. The effect of the increased rate of flow is not only to bring out accumulations in the filter, but to make the new matter brought to the filter pass through it too fast to give time for oxidation, and, therefore, at storm times the suspended matter would be somewhat putrefactive. Our experience in the storm water experiments at Leeds leads us to the conclusion, that where percolating filtration follows any process of thorough settlement, it is quite possible to increase the flow to the filters to six times the normal, say to six million gallons per acre, and by doing so to keep the filters clear of accumulations; but on the other hand, where the sewage is passed crude to the filters, or where septic effluent, or only partly settled sewage is to be used, it would be better not to use the percolating filters also as storm beds to the full amount of six dilutions.

The impurities of storm waters are mainly due to suspended matter, and it will probably be found advisable to settle these out. They can be settled out after filtration, but the increased flow washing out the nitrates causes defective purification for some days after the storm when the filter is normally treating screened sewage. Nor does any washing out of accumulations in a coarse percolating filter appear to be very necessary, for it was found at Leeds that these come out in periodic flushes mostly in the spring, probably because of the disturbance due to the increased development of low forms of life at that season.

Reference has been made in the previous pages to the fine screening of sewage. Screening of Sewage.

There are already various makes of automatic screens, but these, although efficient for coarse screening, were found to be of little use for keeping back the large quantity of fibre in Leeds sewage and the smaller other matters which it was desired to keep off the filters.

A variety of experiments were carried out with screening materials, and screens of about 30 per inch were found to be necessary. It was very difficult to keep these clear, and a series of screens, one finer than the other, were used in succession for a long time. In passing sewage (even after screening through a $\frac{1}{16}$th screen) through a fine sieve of 30 per inch, a thin and almost impervious layer of about $\frac{1}{32}$ inch thick was formed in a few minutes, which made such screening impracticable. After a while, however, we devised a plan of inclined screens, the rush of the sewage washing forward the matter screened off, and ultimately we were able to dispense with the series of screens and use only the finest—30 per inch screen. This fine screen alone followed the coarse one inch grating at the entrance of the works, which kept back sticks, cabbage leaves, large pieces of paper, and generally the coarsest solids. The fine screen kept back fibre, small pieces of paper, matches, tea leaves, and such like, together with smaller particles mixed with them. No automatic method of removing these matters as they were washed forward on the fine screen by the rush of the sewage was actually put to work, for much of the accumulations fell over the bottom edge of the screen into a box, but it would be obviously easy to apply a rotating arrangement to push over the accumulations from the fine screen on to a travelling carrier—which might convey them to a pair of rollers by which the bulk of the water would be squeezed out and the matter delivered in fairly dry condition.

At Leeds it was allowed to remain in a heap, from which the water gradually drained, and the matter was then gladly taken away by neighbours for use in garden frames.

Mr. Precious and Mr. Robinson, two of the workmen, suggested a further improvement in the screening, which was applied and has been since continued, namely, to introduce a tipping trough or box—which received the flow, and, as soon as full, turned the contents over about every ten seconds on the fine inclined screen, thus more effectively washing forward the matter screened off, and giving time to the screen to clear itself of liquid.

At first it seemed as if a considerable proportion of the suspended matter in the sewage was kept back by the fine screen, but, although the accumulation seemed bulky, it was found on drying to represent less than 10 °/₀ of the suspended matters in the sewage. They, however, were of a kind to be very slowly reduced by bacterial action, and were just those which tended to form a felted mat on the surface of the filter, and which it was important to keep back.

Fine screening, therefore, although valuable, still leaves the bulk of the suspended matter in the sewage, but in a finely divided form, which readily works its way down through a percolating filter, becoming reduced and oxidised on the way, coming out as fine brown particles in the nature of earth.

The pumping of the sewage at Leeds, no doubt, breaks up the suspended matter.

Where sewage is to be subjected to settlement before filtration, there seems to be no object in having fine screening, for the matters which would be screened off would be much less expensively kept back by settlement together with the finer matters, so forming sludge to be dealt with by pressing or otherwise.

Fine screening will only be required where it is proposed to dispense entirely with settlement before filtration, and to send the crude sewage on to percolating filters.

These screening experiments, however, are interesting and suggestive, and have for that reason been described.

It should be added that we also tried at Leeds an experiment to remove by centrifugal action the suspended matter in the sewage, but the inventor has not so far been successful.

An inexpensive method of keeping back suspended matter from sewage without formation of sludge would be very valuable.

General Notes on Biological Methods of Sewage Disposal.

Nature's Alchemy.

We cannot fail to be impressed by the automatic and perfect efficiency of nature's alchemy, when we consider that apart altogether from the human race, there is in the world an innumerable population of living creatures as beasts, birds, insects; that great, indeed, must be the daily multitude of their dead; and that to the vast sum of animal there must be added that of vegetable decay.

In Nature's wondrous cycles of change, there is a constant circulation of matter, indestructible indeed, but eminently unstable and constantly changing, death passing into life and life into death. Many of her creatures form the living prey of others, but where the dead, big or small, fall to the ground, her army of "undertakers" at once appear. Sometimes the process is visible enough, as when the vultures gather over the dead camel in the desert, or the crows over their smaller carrion, but more often it is unnoticed though visible, as the rats, the worms, the beetles, the flies, gather to their work, while again it is most often invisible, for some of the agents of the subtle chemical transformation which turn organic decay into the food of plants, are as infinitely small as they are infinitely numerous.

Natural Disposal of Fœcal Matter on Land.

So with the comparatively minor process of the removal of the excreta of living creatures, human or other. Shed upon the earth they disappear, are dissolved into new chemical compounds, pass into the life of plants and so again to that of animals. The natural method of their disposal is over and through the land.

But civilisation, the great concentration of populations, the crowding of communities in great industrial centres, the tempting facility of water carriage for fœcal and other domestic waste, have altered the natural conditions and created the

difficulties which confront us. In addition to the system of water carriage, there is the combined system of sewerage, which adds the surface water to the sewage, greatly increasing its dilution, and in many places this is further increased by the volume of trade effluents.

It is useless to discuss here whether water-closets and drains are a blessing or a curse or necessary evils—or whether it is best to have a combined or separate system of sewers. We have to deal with things as we find them at Leeds, and must assume that their adoption is irreversible. As a result, the problem before us is to deal with a great volume of liquid, foul indeed, and yet so dilute as to have lost much of its manurial value, and to require a vast area for its treatment on land.

Difficulty of Finding Adequate Land Areas.

In the case of small communities surrounded by agricultural districts, the difficulties of sewage disposal are relatively small, and, where levels are suitable, disposal on land is effective and practicable. In the case of the great cities, however, and of the smaller communities so often gathering around them, with only small intervening agricultural areas, the treatment of sewage on land becomes an increasingly difficult problem. Indeed, land treatment in these cases becomes quite impracticable, when we remember how the areas are restricted by the question of levels; how, when a certain area is available, it often proves of unsuitable quality so that it can only deal efficiently with a very small volume per acre, and how we are now called upon to deal not only with the dry weather flow, but also at times with the first five dilutions by rain, which are often fouler than the normal sewage.

It is the difficulty—more often the impossibility—of finding within reasonable distance, and practicable levels, the great areas of land suitable for sewage treatment, that has led Leeds, Manchester, Birmingham and so many other inland cities to carry out experiments in alternative systems of sewage disposal.

Thirty years ago all that was generally thought necessary was to remove the suspended matter from sewage and produce a fairly clear effluent, and therefore methods of chemical precipitation were much in vogue. It is now everywhere recognised that, except for delivery into tidal waters, the dissolved impurities in sewage must also be as far as possible removed. If a sample of average Leeds sewage be filtered through filter paper, the clear liquor will still contain in solution about 50 °/。 of the original impurities, and, on keeping, it will become dark-coloured and putrefy.

When sewage is cleared of the greater part of its suspended matter, the area required for land filtration is less than for crude sewage, but is still considerable ; and, as the same land cannot be continuously used, there must be an ample area of spare land for resting, ploughing and cropping. The area required also depends upon the filtering quality of the land. In the case of clay land it often happens that only some 6 to 12 inches of the upper surface are of any service, and therefore that a very large area is required to give efficient results.

Artificial Filtration Areas.

It is interesting to note that in some cases ashes have been carted on to clay lands and mixed with the shallow surface loam —so as to increase the effective depth of the soil. This is a transition between " land " and so-called " artificial filtration." In other words, where area is limited, compensation must be sought in depth.

An architect in building a factory or workshop may construct a large shed if he has plenty of land, and if not, he is compelled on his limited area to raise a building of many storeys.

In artificial filtration there is used an area specially prepared wholly of material suitable for the purpose, such as burnt clay, coke, clinkers, &c., to any depth or height required, and no attempt is made to use the area for raising crops. The action is of the same character as in land filtration. The

process is not new. What is new is our recently much extended knowledge of the chemical changes that are brought about, of the micro-organisms which are the agents; and of the necessity for effective aeration in order to bring about conditions in which the organisms and the filter can work permanently.

Biological or Bacteria Beds.

The terms "Biological filtration" and "Bacteria beds" are so far misleading that they appear to suggest as peculiar to artificial filtration the action of minute organisms in bringing about chemical changes.

Both in land filtration and in artificial filtration there is (1) a straining off or keeping back of suspended matter, which alone justifies the word "filter" and (2) the much more important work carried out by micro-organisms in transforming the dissolved as well as suspended impurities by oxidation.

Composition of Sewage.

Mr. Dibdin, in his book on "Purification of Sewage," (second edition, p. 6 & 7), there describes the character of the substances predominating in foul water. "First, then, sewage may be considered as containing animal substances, largely composed of fibrine, gelatine, chondrine, albumen, &c., and, secondly, vegetable substances, such as starch and woody fibre (cellulose), gummy matters, with tannin, &c. In the first instance we have to deal with matters which speedily undergo decay by putrefaction when there is not a sufficient supply of oxygen, in which case, however, the decomposition takes place by the action of organisms opposed in general character to those which are the active agents in bringing about the process of purification unaccompanied by offensive adjuncts. These aërobic organisms, as they were called by Pasteur—in contra-distinction to the anaërobic organisms—live only in the presence of air, as their name implies, whilst the anaërobic organisms live in the absence of air. When air is freely present, and the conditions generally favourable, the aërobic organisms destroy

the organic matters in an inoffensive manner. The nitrogenous matters are resolved with either the production of ammonia or the oxides of nitrogen, or possibly the evolution of uncombined nitrogen. The oxygen and hydrogen, forming a considerable portion of the matters, are recombined into water, and the carbon becomes carbon dioxide, or carbonic acid gas, as it is generally called. Similar transformations take place with these elements in vegetable matters, but a longer time is usually required for the completion of the process than is the case with animal substances, as they do not form so suitable a medium for the support of the microbic life. Woody fibre, especially paper pulp, is more refractory, and will require a much longer time for its disruption, but in the end the same transformation occurs, and carbonic acid, water, &c., are formed as a result."

Micro-organisms.

The micro-organisms referred to are of various kinds, as bacteria, fungi, algæ, protozoa. Bacteria, the most important of them, are minute low forms of life, which, under high powers of the microscope appear as small dots or short lines, either straight, curved, or spiral, varying in size from $\frac{1}{5000}$th to $\frac{1}{25000}$th of an inch. They are mostly endowed with motion. These elementary germs exist in nature in countless myriads. They abound in the upper layers of the soil and in foul water. Millions of them have been counted in a cubic centimetre (about a thimbleful) of sewage. Under favourable conditions they develop at an amazing rate. Some of the forms have been identified as disease germs (Pathogenic Bacteria), but for the most part, their action is not only beneficent, but is part of the necessary processes by which continued life is possible on the earth.

Artificial filtration is of two kinds: (A) contact beds and (B) percolating beds. In both cases the transformation of organic impurities is by aerobic organisms. In both cases, efficiency is, therefore, dependent upon aeration.

(A) with contact beds we have water-tight tanks filled with suitable material, into which the sewage flows till the tank is full. Usually, the sewage is allowed to stagnate for a couple of hours in contact with the slime of aerobic bacteria on the surface of the material, and these organisms bring about material change in the sewage, which is then allowed to flow out. As the liquid flows out of the tank, air inevitably replaces it and the surfaces of the material of the filter become exposed to the oxygen of the air. The filter is allowed to rest empty for several hours. During this time, the chemical changes in the suspended solids left behind in the filter is very active, as evidenced by the considerable rise in temperature which takes place in the bed if the period of rest be continued for some days. Contact Beds.

If, as soon as the bed is empty, it is at once re-filled; and still more if a streaming action is continued so as to keep it full of sewage, the purifying action is soon reduced and disappears altogether. The aerobic organisms are, so to speak, drowned, and in due time, their place will be taken by the development of anaerobic organism, and the filter will become a septic tank. The work of aerobic bacteria is only possible with frequently renewed aeration.

No doubt the aerobic changes near the surface of a contact bed are the most active, because as about an hour is usually required to fill, and another to empty the contact bed, the upper part is much better aerated than the lower. Indeed, the bottom of a contact bed, through which the sewage trickles long after the main flow has ceased, often develops, in primary beds or in beds which are more or less choked, anaerobic conditions which account in part for the somewhat unsatisfactory first flow of contact beds. The last flow of contact beds is always the best, because this liquid has slowly trickled down the surface of the material, thus being in intimate contact with the bacterial slime. Analytical results of the

highest quality are then obtained, and could be continuously obtained, if a perfectly even distribution of the sewage at a very slow rate of flow could be continued on the bed. It would then become a percolating filter, and the quality of the results obtained from a percolating filter are in proportion to the rate of flow. During the process of filling, while the sewage is passing down the material to find its level, a contact bed is also working as a percolating filter.

Percolating Beds.

(B) In a percolating filter, although there may be a short intermittence in the distribution of the sewage on the surface, the action is practically continuous, and the maintenance of the aeration is dependent partly on the volume and character of the flow, and partly on the grade of the material. As the filter is not required to stand water pressure, the filter may consist of a levelled area of material without any construction of sides to hold it in. It is generally, however, less costly to construct light walling or other fence to hold up the material than to let this occupy an inclined space round the levelled portion.

At Leeds, in one case, the sides were formed of wood laths held together by light iron bands ; in another there was an open brick wall ; in another a wall composed not of bricks but entirely of agricultural tiles, so as to provide complete side aeration ; while, again, one percolating filter was made with sides of solid walling. Side aeration, if not useless. is of relatively small value, and, if surface aeration ceases, the remaining side aeration does not save the situation, for in the absence of effective surface aeration purification practically ceases.

Importance of Removal of Suspended Matter for Contact Filtration.

The quantity of suspended matter carried to either contact or percolating filtration is a matter of primary importance. A large part of this matter is not digestible by bacterial action ; and, therefore, if it does not come out with the filtrate, it must ultimately choke the filter.

It was found possible to treat crude sewage on contact beds at Leeds, but the primary beds were choked up in less than two years. The same result took place with fine percolating beds, but the choking up was much more rapid. The conclusion reached was that it was better first to remove the bulk of the suspended matter before passing sewage on to either kind of filter. No doubt, with thoroughly clarified sewage containing not more suspended matter than 3 to 4 grains per gallon, the contact beds would last a considerable time; while, if the primary bed has a layer of fine material on the top, it may be practicable to work with sewage containing more suspended matter, because a large part of this will be strained off and kept on the surface of the filter, to be removed after accumulation.

There is, however, always some of this earthy matter which works its way down into the body of the filter, and, with any but thoroughly clarified sewage, the contact beds or the fine percolating filters must choke up, the length of their life being in inverse proportion to the quantity of suspended matter brought by the sewage. At Leeds, septic effluent, with an average of 18 grains suspended matter, has been passed with very good results over double contact beds for over three years, but the capacity of the primary bed has been reduced from 86,900 to 37,600 gallons. Contact beds dealing with effluent from the closed septic tanks have, at the end of four years, reached a condition requiring the renewal or washing of the material. This removal, washing and replacing of the material of contact beds may prove within limits of practicable expense, and it will then be a matter of finance and convenience to decide if it is better to thoroughly settle the suspended matter before sending the sewage to the filters, or to only partly settle it, and put up with the cost of washing the material every four or five years.

Fine Material unsuitable for Percolating Beds at Leeds.

Experience is entirely against the use of fine material for percolating beds for Leeds sewage, and in favour of using such grade of material as will enable the oxidised suspended matter

to work through the filter and come out in the effluent. Thus for over four years the No. 2 percolating filter has dealt with septic effluent night and day at the rate of one million gallons flow per acre, and the filter is still in good order because the material is coarse. The special feature of percolating filters is that, if their material is coarse enough, the filtrate will bring out with it such proportion of the suspended matter as is not digestible—matter which has reached an earthy condition.

The filter then is capable of continued life, because it digests what it can and passes out what is undigested or indigestible.

But for this reason, percolating filters can only produce a result good enough to be considered final, if the sewage passing on to them is thoroughly clarified to begin with. If sewage which comes to the filter is only partly settled either in septic tanks or otherwise, the filtrate will require to have its excess of suspended matter removed by a further process.

Provided such further process is added to remove the oxidised and non-putrescible matter in the filtrate, percolating filters worked at suitable rates of flow give excellent results.

Possibility of Treating Unsettled Sewage on Percolating Filters.

This feature of coarse percolating filtration led us to consider whether crude sewage cannot be dealt with on sufficiently coarse percolating filters, since there must be a further process afterwards to remove suspended matter—by straining or settlement ; in other words, whether settlement before filtration cannot be abandoned in favour of settlement after filtration, the latter producing a sludge smaller in volume and far less putrescible than that produced by the former. The interesting experiments in this direction have already been described in this report, and suggest that such method of working may prove practicable if certain difficulties are overcome, and, if so, that it would probably be less likely to give rise to nuisance than any other method of sewage disposal. (See p. 102.)

The experience gained at Leeds, as evidenced by the analytical tables given in this Report, shows that both by contact bed filtration and by percolating filtration excellent results can be obtained under proper conditions with Leeds sewage, and that the large volume and variety of the trade effluents which it contains does not vitiate the process, although it to some extent reduces its effectiveness, because some of these liquids take up oxygen which otherwise would be available for oxidising the organic matter.

Purification Obtainable by Artificial Filters.

Indeed, it may be said that any desired standard of purification can be obtained by artificial filtration. It is merely a question of what is financially practicable.

Thus, while single contact filtration of septic effluent did not give results quite good enough, double contact filtration gave a purification well within the provisional standards of the Rivers Board; and, no doubt, triple and quadruple contact, which, however, would be prohibitively costly, would give very high results indeed. So with percolating filtration, while the filtration of septic effluent at the rate of one million gallons per acre over very coarse material gave excellent results, after the filtrate had been passed through a few inches of fine material to keep out the oxidised suspended matter, there can be no doubt that a slower rate of flow followed by settlement, and afterwards by sand filtration, would also give very high figures of purification.

We are of opinion that, although effective sewage purification must always be costly, the conditions under which satisfactory results can be obtained in the filtration of Leeds sewage on artificial areas, are within the limits of financial practicability.

On the other hand, if it is attempted to deal with sewage over an inadequate area of filters, unsatisfactory results will follow, just as they do in land filtration, when, as so often happens, sewage farms are overworked and the land becomes

Artificial Filters like land, must not be overworked.

"sewage sick." And just as in land treatment the area must be sufficiently great to allow of the sewage being turned off from certain areas for long periods so as to give those lands time to recover by ploughing over and by rest, or even by cropping, so with artificial areas, especially of contact beds, there must be sufficient filters to allow of periods of rest; and expense will have to be incurred in turning over the surface, or removing accumulations, or even washing and replacing the material.

Difficulties to be overcome.

There are, however, certain difficulties to be overcome in connection with artificial filtration, which, no doubt, later experience will solve. It will be useful to refer to the more important.

(1) *The question of the material to be used.* Coke was found to give better results at Leeds than clinkers, because the particular clinker used proved to be very friable. The chemical character of the material is much less important than the physical, such as the grade, the form, the surface and the power to resist degradation. The porosity of coke or any other material is of no lasting value, for the pores soon get filled up by water, which is held up by capillary attraction. On the other hand, a polished surface like that of glass would be unsuitable, because the suspended matter and the bacterial slime would too readily washed off by the flow of sewage.

Best Material for Beds.

Therefore, until the site of the new sewage works is finally settled, it is difficult to say what material should be recommended. A great variety of material can be used with good results, and we have seen filters in which coke, coal, clinker, stone chippings, broken brick, coarse shingle or gravel, or broken up saggars such as are a waste product in the potteries, have been used. In the choice of material, the local opportunities of obtaining it and the cost of carriage must be taken into account. The really important factors are:

(1) *Suitable grade.*

(2) *Permanence.* That is, resistance to degradation. If a certain grade or size is selected as the most suitable to the purpose, then the material which will longest resist the tendency to break down into smaller size will be the best.

The inadequately vitrified clinker from the destructors at Leeds broke up very rapidly, especially on the surface exposed to weather, and so caused the failure of several experiments. Gas coke resisted longer, but still disintegrated much too rapidly. Hard furnace coke and broken bricks were much more durable.

(3) *Equality of grade.* Whatever grade is selected, it should be as far as possible all of one size and not consist of a variety of sizes. The effect of uneven grade is that, especially in contact beds by the movement which follows on alternate filling and emptying, the small pieces tend to work into the spaces between the larger, and so to bring about consolidation, which is a more serious cause of loss of capacity in contact beds than the accumulation of suspended matter. And even if at first the material is of fairly even size, degradation soon contributes towards consolidation. The friable Leeds destructor clinker used in beds No. 7 and 8 was found, after a few months, to have consolidated into an almost solid mass. (See p. 78).

Flat sided material like half bricks is apt to fall into positions wasteful of the intervening spaces. Mr. Dibdin's proposal to use slates placed horizontally and kept separate by small pieces of coke may be worth trying for contact beds, but would be useless for percolating beds. On the whole, the irregular lumps which are available with coke, clinker, broken brick, &c., have proved convenient, but the air spaces are very irregular, and the large surfaces of contact hold up much water and accumulation of solid matter.

Ideal Material for Filter Beds

Let us consider what should be the ideal material for artificial filters; what should be its form and what its physical character?

The ideal material must be of perfectly regular size; and of such form that it will give the maximum of surface for a given bulk of matter; the points of contact must be as few and as small as possible; the intervening spaces must be regular and as large as possible; the material must be hard so as to preserve its form unbroken as long as possible.

The spherical form best fulfils these conditions.

If spheres or balls be stacked regularly within a given cubic space, there will be a constant relation between the space occupied by the material and the intervening spaces, and this will be so whatever the diameter of the balls. Thus: a cubical tank of 3 feet measure would have a capacity of 27 cubic feet. If one solid sphere 3 feet diameter were put into it, this would take up 14·13 cubic feet, and leave a water capacity of 12·87 cubic feet. If again, instead of the single sphere, 27 spheres each of one foot diameter are stacked in this 3 feet cubical tank, each sphere has solid contents of ·543 cubic feet, and the whole 27 will take up 14·13 cubic feet, leaving a net water capacity of 12·87 cubic feet, which is the same as in the preceding case, and equal to $47\frac{1}{2}$ °/₀ of the capacity of the tank.

If stacked in the closest possible positions (as seen in piles of round shot), the 3 ft. cube would contain $31\frac{1}{2}$ spheres of 12 inch diameter, provided it formed part of a larger tank. These would have a volume of 16·5 cubic feet and have a water capacity of 38·8 °/₀. In practice, however, the balls used for filter material would fall into less regular positions, leaving arched spaces here and there—as with other iorms of material—and the water capacity would probably be about 50 °/₀ of the tank capacity.

But while the capacity will be the same, whether large or small spherical material of equal size be used, on the other hand the available surface area of the material will be greatly larger with small than with large spheres.

It is very necessary to keep this point in mind when selecting the size of the balls, which must be as small as practicable consistently with the safe maintenance of the air spaces.

Now, if we are right about the spherical being the ideal form, the practical question arises, where are these balls to come from? They don't exist in nature in sufficiently hard and enduring form, nor do they arise in waste products so far as we know, and therefore they would have to be manufactured; and we believe that it is financially practicable to produce them in hard burnt clay.

If it should prove impracticable to obtain spherical material within reasonable limits of cost, then the aim should be to get material approximating roughly to the shape of a ball.

If a primary contact bed dealing with septic effluent were constructed of 3 inch balls, would it pass out the undigested matter owing to the ample and regular character of the spaces? or, if not, would it be possible to wash out accumulations periodically without removing the material? Spherical material should be as valuable for contact as for percolating beds.

The whole question of spherical hard material for artificial filters, especially of the percolating kind, is well worth going into.

We may now pass from the difficulty of the material to that of the *distribution of sewage on to artificial filters.* Distribution of Sewage into Filter Beds.

In the first experiments with contact beds in 1897, we used a rather elaborate arrangement of wooden distributing channels about 6 inches wide and high, pierced with holes at the bottom and sides. These were unsatisfactory, because of the settlement of suspended matter which constantly choked up the holes. Ultimately these channels were given up, and the distribution

on beds No. 3 and 4 and 5 and 6 was by flowing the sewage in a thin film over a lip or weir of the whole width of the bed. As soon as the immediate surface below the lip was choked, the sewage spread further over the bed until after a few months it had spread to the far side, and it became necessary to fork over the surface, and even to remove the surface accumulations. In the later experiments the surface of the beds was hollowed out into grips or channels lined with fine material, along which the sewage flowed, and when these became choked, the obstructive layer was raked off into heaps, and when necessary, at long intervals, new channels were dug along side the old, which were filled in with excavated material. In practice this was found the best and cheapest way; but as contact beds during the process of filling are acting as percolating beds in the upper portions, it would theoretically be much better to feed the sewage in a rain over the whole surface.

For the percolating beds the sprinklers used were none of them very satisfactory. Fountain sprinklers or nozzles such as used at Salford were found to rapidly choke with fungoid growths when used with septic effluent or partially settled sewage at Leeds. All the rotary sprinklers working on the Barker's mill principle gave trouble because the holes in the arms through which the sewage fell into the filter choked with growths and required daily cleaning, and it was difficult to vary sufficiently the rates of flow. The question of the sprinklers, however, did not receive much attention, because it was felt that with filters carried out on a large scale, a different method of distribution altogether would be required. At one time we considered the ideal distribution for a percolating filter to be a gentle rain of sewage continuously on the surface. We are inclined, however, to think that, although intermittence of feed on a coarse filter has its disadvantages, that on the whole, some intermittence is useful, improves aeration, and tends to check the surface growth of fungus which has always been rather a trouble on percolating beds at Leeds. Therefore, as a rule, the sprinklers were worked

so as to feed during one minute, and to stand during two to four minutes. During the periods of starting and stopping there was irregular distribution, which is a great evil. We doubt whether for distribution on a large scale, the sewage itself will be used for the motive power. By having an independent motive power, there will be greater control over the rate of flow and the intermittence. With a circular septic tank surrounded by a belt of percolating filter, with a rail on either side of it, there could be fitted a carriage and a motor—preferably electric—which would syphon the sewage from a circular chamber round the circular tank and pass it over a lip on the carriage to flow at a regular and continuous speed upon the material. The carriage travelling round the circle at any desired speed, while there would be no interruption in the flow of the sewage, would move forward over different parts of the surface, and each part, after receiving its share, would have some minutes rest during which the liquid passing down into the body of the filter would draw air in after it. This air would itself be driven down by the next flow of liquid, which would act as a sort of piston in a cylinder working from upwards downwards.

Mr. Scott-Moncrieff has fitted up at Birmingham a motor carriage working round a pivot to distribute sewage over a large circular percolating bed. This apparatus has the advantage of flowing the sewage over a lip instead of through holes, and the regulation of the flow is ingenious and satisfactory. The sprinkler is driven by an oil engine, and the only difficulty about it is that its construction is at present too costly.

It seems to us more likely, however, that in a large installation the percolating filters would be in the form of long rectangles. Long, because the width would be limited by the practicable span of the carriage across its rails, one in the centre and others at each side of the filter; while the length may be much more considerable, being only limited by the

intermittence of flow which it may be desired not to exceed. The motor would traverse the carriage to the end of the filter, and then reverse the action.

A very good arrangement of this kind has recently been designed for Hanley, upon long rectangular percolating beds, and in this case a good feature is that on the forward movement one-half of the bed is sprinkled, while the other half is sprinkled on the return. The motive power is electricity, and the feed is through holes. For Leeds sewage, feeding through holes is sure to be unsatisfactory, and feeding over a lip or weir would be much better. Whatever arrangement is adopted, it must be possible to regulate the flow to anything that may be required, and likewise the length of the intermittence.

Equality of distribution over all the surface is an essential of successful percolating filtration.

Fungoid Growths.

A few words must be added in regard to the difficulty of the *fungoid growths* which arise in dealing with Leeds sewage upon percolating filters, and which with any but very coarse material, soon choke the air spaces, and cause the sewage to pond on the surface. The growths were less with partly settled sewage than with the crude sewage, and as in either case they did not spread far down into the filter, not more than from 6 to 12 inches at most, it would seem that light is required for their development. On the other hand, the holes in the sprinkler tubes were constantly choked with these growths so that they required to be daily cleansed; but it is more likely that this was due to the fungus which forms in the open channels leading to the sprinkler being washed forward into the tubes, than to the growth arising in the tubes themselves. It is quite possible that sewage thoroughly well settled may give rise to fungoid growths, the detritus from which may cause suspended matters to appear in a filtrate.

The question of these growths and the circumstances which favour their development is one that should be further investigated.

While on this subject it will be useful to point out that vegetable growths of various kinds arise in all water channels, where the speed of flow is not too great to permit of their formation, and they probably fulfil some useful purpose of purification by the absorption of nitrogenous matter. It is very useful to take note of these growths in connection with sewage effluents, as they are characteristic of the degree of purity of the flowing liquid. Indeed, it may be said that a sewage effluent registers its conditions on the walls of the channels through which it flows. Thus, at Leeds, in the channels along which passed septic effluent, the walls were covered nearly an inch thick with black, brown or grey growths; the effluents from the single contact filtration of septic effluent produced brown and grey growths which differed from these, while in the basins and channels through which passed the effluents from double contact filtration, there were no growths of this character at all, but green confervoid vegetation, which is always characteristic of a well aerated effluent.

Physiological Character of Effluents.

In the Leeds experiments the effluents were caused to pass through basins about 10 by 10 ft., divided into two depths of 4 ft. and 2 ft., and flowing thence over a lip. These basins were very useful in enabling a sample of the last flow to be always left behind in evidence, and also for noting the kind of growths to which the effluent gave rise. There was further the advantage of ascertaining how far certain effluents, undiluted by river water, could sustain fish life.

If an effluent passing through such a basin develops green growths, and if coarse fish—snch as gold carp—are found to live and thrive in it for months and even years, there can be no better evidence of purification.

The basins through which flowed the filtrates from the Leeds coarse percolating filters did not, either in regard to green growths or the sustaining of fish life, give so good results as those obtained in the basins from the double contact filtration; and this, although the filtrates were usually better aerated, containing generally nearly 5 c.c. of dissolved oxygen per litre. It may be taken as certain that in this case the large quantity of earthy suspended matter in a finely divided condition which the filtrate contained, tended to choke the gills of the fish, which however lived for months in the flow of these filtrates. There was no basin available for testing the conditions after the settled matter had been kept back by the shallow fine filters.

Purification Tests.

The previous observations naturally lead us to consider by what tests we should judge of the quality of effluents. Apart from the quantity of suspended matter, which of course must be limited, the practical issue is whether the effluent after it leaves the works will be liable to putrefaction, and so to cause nuisance.

At the present time the Rivers Boards of Lancashire and of Yorkshire have in practice adopted a chemical standard for effluents, which is that they shall not take more oxygen than 1 grain per gallon from permanganate in four hours at 80°; and that they shall not show more than ·1 grain per gallon of albumenoid ammonia by the Wanklyn test.

Dissolved Oxygen Test.

In addition to this there is also the Incubation test, and latterly the experts of the Royal Commission have recommended the dissolved oxygen test, which no doubt is the most reliable test for a good effluent.

If an effluent has been saturated with oxygen, and at the end of 24 hours still contains not less than 50 to 60 °/$_0$ of it, it may be taken that it will not bring about any nuisance by taking up oxygen from a stream into which it may flow. Very good effluents are found to retain 90 °/$_0$ of their dissolved oxygen after 24 hours.

The oxygen contained in an effluent in the form of nitrates is also an important point to take into account, and in many cases effluents, containing considerably more organic impurity than would be allowed by the provisional chemical standard referred to, have been found quite safe from subsequent putrefaction, because of the oxygen available in the nitrates—or the dissolved oxygen present—which have sufficed for the oxidation of the remaining organic matter.

In Leeds, owing to the presence of large quantities of trade effluents in the sewage—many of which take up oxygen which otherwise would be available for the purification of the organic matter—the proportion of nitrates produced in the processes of filtration have, under normal conditions, never risen to the figures obtained elsewhere with mere domestic sewage, but have ranged from ·5 to 1·5 grains per gallon, although in special circumstances, of course, these figures have been exceeded.

On the other hand, the average amount of dissolved oxygen in the effluents from double contact filtration of septic effluent has been 3 to 5 c.c. per litre, and that from percolating filtration 5 to 6 c.c.

The large quantity of dissolved oxygen in the effluents from percolating filtration is a strong point in its favour.

In some cases reliance has been placed upon the dilution of the stream into which the effluent flows to supply the necessary oxygen to purify the organic impurities remaining in an effluent, but it is much safer to produce an effluent which undiluted will not putrefy, and if an effluent by itself contains and retains sufficient dissolved oxygen to support fish life and give rise to green growths, it may be considered a safe effluent. If all the authorities above Leeds produced such an effluent, the evil reputation of the river Aire would soon pass away ; and broad streets and quays might border the river and transform the appearance of the City.

Relative merits of Contact and Percolating Filtration.

Judged by any of these tests, both systems of artificial filtration gave satisfactory results at Leeds, and it is merely a matter of financial practicability to obtain by either of them purification of any degree of excellence that may be desired. Relative cost of construction is a matter that must depend largely on the levels and character of the site which will be selected for the works, and is a matter of engineering outside the range of this Report. On the other hand, the volume of sewage that may be dealt with per cube yard on either system is a point upon which the Leeds experiments enable us to give data.

(1) As to *crude sewage*; that is sewage which has been screened as far as possible, but not settled. It was not found practicable to deal with such at all on contact beds because of the rapid choking of the primary beds, but the experiment described earlier in this Report shows that it was possible to deal with crude sewage at the rate of one million gallons per acre, or 200 gallons per square yard, or 50 gallons per cube yard, on very coarse percolating filters 12 feet deep. In this case the filtration is an intermediate process, and must be followed by settlement, or fine filtration, or both.

(2) As to *septic effluent*, or *settled sewage* from which suspended matter has been removed down to about 10 grains per gallon.

In this case excellent results were obtained by double contact filtration over a period of several years with septic effluent at the average rate of 744,000 gallons per acre on the primary bed, 5 feet deep. This is equal to 153 gallons per square yard, or 91 gallons per cube yard, and would require 1·34 acres of primary bed per million gallons. To obtain the results desired a second contact bed must follow, so that taking into account the double process the rate per cube yard would be 45·5 gallons, and a combined area of 2·68 acres would be required for one million gallons.

These figures are based on the experiment with beds of ⅛ acre area—detailed on pages 68 to 70. The average volume of a filling taken over the whole period was 60,000 gallons. There were two fillings a day, with a rest one week in four.

At the end of five years the economical point had been reached when it would be necessary to restore capacity by washing the material.

On coarse percolating filters, septic sewage, or settled sewage with about the same quantity of suspended matter, was passed for long periods over a bed 9 feet 6 inches deep at the rate of one million gallons per acre, or 200 gallons per square yard, or 66 gallons per cube yard. The process required to be followed by a further one to separate out the oxidised suspended matter.

(3) With *thoroughly settled sewage* containing only from 3 to 4 grains per gallon of suspended matter, satisfactory results were obtained on a coarse percolating bed 6 feet deep, at the rate of one million gallons per acre, or 200 gallons per square yard, or 100 gallons per cube yard; and in this case no further process was required.

No experiments were made with thoroughly settled sewage at Leeds, on contact beds; but it seems likely that such sewage could be passed at the rate of three fillings a day with an occasional rest. It is very doubtful whether with more than three fillings a day there would be sufficient time for adequate aeration, unless the increased number of fillings were continued for a very short time only.

With percolating filters the rate of flow could be increased at times of storms to as much as six million gallons per acre, or 600 gallons per cube yard for short periods, if the dilute sewage had had its suspended matter fully removed by settlement.

As already pointed out unsettled storm waters, which always contain a great quantity of suspended matter, while they may be passed over coarse percolating filters which are followed by

settlement, tend to put the filters in bad condition for some days after, and wash out much suspended matter which owing to the high rate of flow has not had time to become sufficiently oxidised.

Probably the thorough settlement of the suspended matter from storm waters may prove to be sufficient treatment, for after such settlement the sewage is usually very dilute ; but the clarified dilute sewage may be used with advantage at an increased rate of flow where it is desired to wash out accumulations from percolating filters, or to bring the storm waters to a higher degree of purification.

Smaller Area required for Percolating than for Contact Filtration.

Briefly then, in regard to the work which can be got out of contact and percolating filters, the Leeds experiments show that a cube yard of the latter is able to purify a larger volume of sewage per day than a cube yard used for contact filtration, and that there is more elasticity in regard to the rate of occasionally increased flow with percolating than with contact beds. Inasmuch as good results can be obtained by the use of an adequate area on either plan, the choice must be guided by other considerations, and largely by the method selected for removing suspended matter.

Removal of Suspended Matter.

The experiments detailed in this report show how important is the question of the suspended matter in sewage. By bacterial processes the oxidation of dissolved impurities is rapid and easy, but that of the suspended matter is very slow, and there is always a large irreducible residuum.

No doubt the thorough settlement of the suspended matter greatly facilitates the subsequent process of filtration ; in the case of contact beds secures the maintenance of a fairly constant capacity for long periods ; while with percolating filters it does away with the necessity of a further process. On the other hand the thorough clarification of sewage, which can only be accomplished with the assistance of chemical precipitation,

involves the production of an enormous quantity of sludge; and unless considerable areas of land are available to deal with it as sludge, it involves also great expense in pressing the sludge into cake so that it can be handled and removed on to land.

In many cases it is impracticable to deal locally with such large quantities of sludge or cake, and therefore the treatment of the sewage by septic settlement becomes of value, although about 25 °/o of the suspended matter has still to be dealt with on the filters. Sludge difficulties.

In the example given at p. 61, chemical precipitation gave 49 grains per gallon of solid matter in the sludge and 3 grains to be dealt with on the filters; while septic settlement gave only 16 grains left in the septic sludge, with 13 grains to be dealt with on the filters.

These 13 grains per gallon are with suitable contact beds kept to a great extent on the surface, and can be thence readily removed as they accumulate, while to some extent they will get down into the body of the bed, and so gradually reduce capacity.

In the case of the percolating filters, the 13 grains going on to the filters will of necessity mean that a part of this will come out with the filtrate, and although well oxidised at times of normal flow, will have to be settled or otherwise separated out by a further process.

In some circumstances, therefore, it is better to have to deal with the smaller quantity of sludge produced by septic tanks, even at the cost of dealing with a larger quantity of suspended matter on the filters.

The process of septic treatment is a biological one, for there is not only a settlement of suspended matter, but transformation of it, either into gaseous or liquid products, or into other solid conditions. The bacterial action in this case is by different

organisms to those at work in the filters. These last are aerobic, but those of the septic action are anaerobic, that is, are organisms working in the absence of air. The digestion of solid matter in the septic tanks at Leeds is estimated at 30% of the quantity originally in the sewage.

There is, of course, some digestion of the suspended matter in the process of filtration, but it has not been possible to estimate this with sufficient accuracy to make it worth while to give the data. The quantity of suspended matter going on to the filters is very variable, and it is almost impossible to measure the accumulations on the surface and in the body of contact beds; while with percolating filters, much solid matter accumulates in the filter, to be washed out in periodical flushes at certain seasons, as already pointed out.

Chemical Precipitation or Septic Settlement.

Now, whether thorough settlement by chemical precipitation, or whether septic settlement should be used as a preliminary process, must necessarily depend on local circumstances. And in the case of Leeds it is impossible in the present position of the new sewage schemes to express a definite opinion.

It is true that a distant site, the Gateforth Estate, has been secured; but Parliament threw out in 1901 the bill to obtain powers to carry the sewage to it. Since then various proposals have been made to carry the sewage in a steel pipe or in several steel pipes, with the view of avoiding the objections raised to the original scheme. The single pipe scheme involved of necessity the thorough settlement of the sewage before passing it in the pipe to Gateforth because of the slow speed of flow, and it was proposed in that scheme to deal with the huge quantity of sludge that would be produced by pressing it into cake, conveying this to Gateforth by canal, and there ploughing it into the land. On the other hand, with several steel pipes, preliminary clarification would not be necessary; while, again, if it should prove ultimately possible to secure a sufficient area of land near the present works, the conditions would be completely altered.

The various experiments carried out at Knostrop from 1897 to 1905, the description of which form the subject of this Report, have shewn the conditions which are necessary to success in the treatment of Leeds sewage, and will doubtless be of interest and value wherever the difficult problems of sewage disposal are being studied.